SURVEY OF *BOMBUS* SPECIES (HYMENOPTERA: APIDAE) NEAR AGRICULTURAL LANDS IN INTERIOR ALASKA

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A

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ABSTRACT

Major world pollinators include bees, beetles, flies, butterflies, birds and bats, all of which help pollinate over 75% of Earth's flowering plant species and nearly 75% of the crops. In arctic and subarctic regions, bumble bees are considered important pollinators; however, immediate concerns involving climate change, colony collapse disorders in honey bees, and lack of faunistic insect studies in Alaska emphasize the need to study bumble bees in interior Alaska. Seventeen species of bumble bees were identified from three localities: Delta Junction, Fairbanks, and Palmer, Alaska. Not all species were recovered from all localities and species richness and relative abundance varied by years. Delta Junction displayed the highest relative bumble bee abundance representing approximately 50% of the overall total of bumble bees collected during the two year study. Overall, the most common bumble bees near agricultural lands were *B. centralis, B. frigidus, B. jonellus, B. melanopygus, B. mixtus,* and *B. occidentalis.* Their populations and local diversity were highly variable from year to year. A species believed to be in decline in the Pacific North West states, *B. occidentalis*, was collected in relative abundance up to 13.5%; this species was collected from the three sites studied. Preliminary data indicates that bumble bees were found to be infected by *Nosema* and nematodes with infection rates up to 12.5% and 16.7% for *Nosema* and nematodes respectively. Of the eight species infected by parasites, *B. occidentalis* displayed the highest *Nosema* infection, while *B. centralis* was the species with the highest infection of nematodes.

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CHAPTER 1. INTRODUCTION

The United States Department of Agriculture (USDA) and United States Forest Service (USFS) estimate that more than 150 food crops in the US, including almost all fruit and some grain crops, depend on insect pollinators (USFS and USDA 2010). The estimated worth of these pollinators is more than $10 billion per year (USFS and USDA 2010). Of the major food crops grown in the United States, common honey bees (*Apis mellifera* L.) are typically given sole credit for pollination, but native bees, butterflies, moths, and flies play roles in crop pollination that are often as or more significant than those managed by honey bees (Roubik 1995; Buchmann and Nabhan 1996). Native bees, such as bumble bees, may be responsible for almost $3.07 billion of fruits and vegetables produced in the US (Losey and Vaughan 2006). No published estimates on the value of bumble bee pollination for crops in Alaska are available.

According to Morse and Calderone (2000), the most common domesticated pollinator species used in North America, *A. mellifera*, was reported to provide services to crops worth an estimated $14.8 billion annually. Imports of pollinators are becoming problematic with high transportation and packaging costs, disease, and concerns regarding non native species affecting native beneficial insects and habitat. Also, honey bees are undergoing extensive die-offs which do not appear to have a single underlying cause (USDA-ARS 2009). This phenomenon has been termed Colony Collapse Disorder (CCD) (Bromenshenk et al. 2010). Recently, however, it has been reported that the co-infection by invertebrate iridescent viruses with a microsporidian of the genus *Nosema* could be the probable cause of honey bee colony decline (Bromenshenk et al. 2010). Some scientists predict that native bees will buffer potential declines in agricultural production due to CCD (Kremen 2005; Kremen and Ostfeld 2005; Winfree et al. 2007), but in many cases, as in Alaska, the native bee fauna is little known.

Bumble bees (genus *Bombus*) and parasitic bumble bees (subgenus *Psithyrus*) can sometimes prove to be more efficient than honey bees (Stubbs and Drummond 2001) in crop pollination, especially when adequate habitat is available near agricultural fields (USDA 2006). Only in areas of extensive and intensive agriculture where natural habitat is limited, bumble bee communities may be insufficient to replace the pollination services currently provided by honey bees (Goulson et al. 2008). In Alaska, only 25,719 acres of the total 365 million acres is cultivated in crops (Benz et al. 2009). Two hundred ninety-six acres of those crops are

vegetables that might benefit from insect pollination. Crops that require insect pollination that might benefit from bumble bee pollination includes canola, sunflower, tomatoes, peppers, strawberries, cucumbers, squash, gourds, pumpkins, mustard, and some annual forage legumes (Free 1993). Countless stands of wild berries such as blueberries, lingonberries, and cloudberries, occur throughout Alaska that benefit from bumble bee pollination (Davis 2002; NRCS 2006).

Bumble bees tend to have longer tongues that allow them to pollinate long, narrow corollas or flowers, and will forage during rainy, cool, and windy weather during which honey bee activity is limited (Buchmann 1983; National Biological Information Infrastructure 2009). Bumble bees have the capacity to buzz pollinate (Kevan et al. 1991; King 1993), a resonant vibration caused when the insect grabs onto the flower and moves its flight muscles rapidly, causing the anthers to vibrate thereby dislodging pollen.

Commercially-produced bumble bees have frequently been used for pollination services worldwide typically in greenhouses (Kwon 2008). The earth bumble bee, *Bombus terrestris* L., is the most common species that has been domesticated and used for commercial pollination for crops in Europe, Australia, Israel, Japan, and Korea (Kwon 2008). This species was originally distributed widely in Europe (Kwon 2008). In North America, native bumble bees such as *Bombus occidentalis* Greene and *Bombus impatiens* Cresson have been domesticated (Kwon 2008). In the past, producers in Alaska have experimented with bumble bees for greenhouse use, but it is not a commercial practice (P. Holloway, pers. comm.).

Commercialized colonies tend to have greater parasitic loads than wild colonies including the bumble bee specific protozoan pathogens *Crithidia bombi* Lipa and Triggiani (Kinetoplastida: Trypanosomatidae), *Nosema bombi* Fantham and Porter (Microsporidia: Nosematidae), and the tracheal mite *Locustacarus buchneri Stammer* (Acari: Podapolipidae) (Colla et al. 2006). These pathogens and mites can have negative effects on imported and native colony survival, reproduction, and/or the foraging efficiency of individual workers (Brown et al. 2003; Whittington and Winston 2003; Gegear et al. 2005; and Otterstatter et al. 2005). Only one published report is available regarding bumble bee pathogens in Alaska. It identifies two distinct lineages of *C. bombi* occurring in Alaska (Schmid-Hempel and Tognazzo 2010).

Impoverished native bumble bee communities often are associated with the intensification of agriculture (high inputs of capital, labor, or heavy usage of technologies such as pesticides and chemical fertilizers relative to land area) and may be insufficient to replace the pollination services currently provided by honey bees (Goulson et al. 2008). Alaskan farms tend to be surrounded by native vegetation and habitat that would benefit native bee populations, but there is little information on bumble bee species composition, geographical distribution, biology, and factors affecting bumble bee species richness in this state.

The objectives of this study were:

- To provide baseline data on species composition, distribution, and seasonal biology of the genus *Bombus* at three agricultural locations within Alaska: Delta Junction, and Palmer;
- To assess presence of *Nosema* that could affect native *Bombus* species; and
- To develop a pictorial key to identify common bumble bee species in interior Alaska.

CHAPTER 2. LITERATURE REVIEW

2.1 Bumble Bees

There are approximately 246 *Bombus* species worldwide; 44 are known from the US and Canada (Williams 1998). Bumble bees can be found among alpine, temperate, and arctic environments of the northern continents. In the southern hemisphere, they are native only in the East Indies and South America. (Williams 1994). They are generally recognized by their furry, brightly colored hair, the presence of meta-tibial spurs, the absence of hairs on the compound eyes, and the absence of the jugal lobe of the hind wing (Thorp et al. 1983).

Their color patterns can vary within species in a region and even more so geographically (Thorp et al. 1983). There are nearly 2,800 bumble bee names that have been published for the 246 species due to identifications based on color (Williams 1994). Alaskan bumble bees tend to exhibit only one color pattern per species; however, males of the subgenus *Psithyrus* have shown considerable sexual dimorphism (Thorp et al. 1983).

Bumble bees and cuckoo bumble bees (parasitic bumble bees) belong to the tribe Bombini of the family Apidae (Kearns and Thomson 2001; Michener 2007). Bumble bees have been placed in several different taxonomic groups based on behavioral and ecological attributes. Recent classifications are based on male genitalia and place all species in a single genus, *Bombus* (meaning 'booming'), and parasitic bumble bees are placed in the subgenus *Psithyrus* (Goulson 2003). A list of the bumble bees reported from Alaska, their distribution, and taxonomy from published sources is shown in Table 2.1.

The development, behavior, and biology of bumble bees and cuckoo bumble bees have been reviewed by Kearns and Thomson (2001). Bumble bees construct wax nests and are eusocial in that they have overlapping adult generations, cooperative brood care, and presence of sterile workers (Kearns and Thomson 2001). Fertilized queens emerge from hibernation each spring and individually start a new colony. The colony develops and grows as workers (females) are produced and start to forage. Unfertilized eggs (males) are laid and subsequent worker larvae develop into new queens. Each fall, males and the new queens mate, the colony disintegrates, and the old queen, workers and males die as the new queens hibernate. Cuckoo females enter the bumble bee nest later in the summer, kill the resident queen and begin laying

eggs. The workers will then feed and nurture the cuckoo eggs. The parasite larvae emerge as male and female reproductive forms, never as worker bees.

2.2 Diel Patterns

Bumble bees are diurnal (Fisher and Tuckerman 1986). During free flight, bumble bees can maintain a body temperature of more than 20°C above ambient temperature by activating thoracic muscles (Heinrich 1972, 1974) which enables them to forage during rainy, cool and windy weather (Free 1993; National Biological Information Infrastructure 2009). According to Heinrich (1979), bumble bees can be seen foraging in temperatures as cold as -3.6°C. They have even been observed foraging during snowfall and under a full moon (Kearns and Thomson 2001). Two studies conducted near arctic latitudes (North Sweden at 68° 22' N, 18° 47' E and Lake Hazen, Canada at 81° 50' N, 70° 25'W), areas above tree line, observed activity throughout the 24 hour period with lowered activity during the middle of the night (Richards 1973; Lundberg 1980). Influences on flight activity can include light, temperature, wind, and rain (Lundberg 1980; Corbet et al. 1993). Preliminary data from Alaska (Davis 2002) suggests that some species are active between 06:00 and 18:00 hours. However, that study only included twelve *Bombus* specimens in a single site in the Fairbanks area.

2.3 Bumble Bee Decline

The conservation status of native bumble bees across North America is lacking due to the limited long-term monitoring and baseline data available (Berenbaum et al. 2007) as is the case in Alaska. However, the health status of native Alaskan bumble bee populations is entirely unknown. There have been studies on pollination biology, particularly on lingonberries and arctic flowers which provide a list of pollinators, but these studies include little population or health status data on selected groups (Armbruster and Guinn 1989; Kevan 1972; Davis et al. 2003).

Nevertheless, there is evidence for bumble bee decline particularly in developed regions such as North America and Western Europe (Allen-Wardell et al. 1998; Thorp and Shepherd 2005; Kosior et al. 2007; FAO 2008; Goulson et al. 2008; Grixti et al. 2009). Potential causes of bumble bee decline outside of Alaska (and potentially in Alaska) include reductions in floral resources, loss of nest sites, invasive species (both plant and insect species), habitat fragmentation, parasitic spillover (from domesticated bees), competition, and use of pesticides

(Kevan 1999; Berenbaum et al. 2007; Kremen et al. 2007; FAO 2008; Goulson et al. 2008). Causes can vary by location, but the above all have negative impacts on pollinator populations. Reductions in floral resources and loss of nest sites can be the result of the expansion of intensive agriculture as well as increasing urbanization resulting in cleared land for highways, houses, and industrial development (Goulson et al. 2008). Pesticides can be highly toxic and there are three possible routes of exposure: direct contact with sprays, contact with contaminated foliage, and uptake of chemicals in nectar (Goulson et al. 2008).

Since 1998, *B. occidentalis* has disappeared from parts of its range which extends from Alaska to central California and east to northern Nevada, Arizona, and New Mexico and is thought to be near extinction (Thorp and Shepherd 2005). This species has been placed on the Xerces Society for Invertebrate Conservation Red List of pollinator insects as a result of its decline (Thorp and Shepherd 2005). Williams and Osborne (2009) suggest *B. occidentalis* be added to the International Union for Conservation of Nature Red-List under the category, endangered. Not seen since 1997 in the Willamette Valley, Rao and Stephen (2007) collected three *B. occidentalis* workers while studying native bee diversity and abundance in 2006. The Xerces Society is documenting the former and current ranges of this species. Appendix C provides some best management practices for land owners regarding bumble bee conservation and management.

Alternatively, Roubik (2001) proposes that the evidence of decline can be misleading. His study focused on the *Euglossine* bee species in Panama over a 20 year period accompanied by three strong El Niño events and concluded that populations and local diversity can be highly variable from year to year (Roubik 2001). He observed that bee populations commonly halved or doubled in one year intervals and suggests that a minimum of four years is required to document decline (Roubik 2001). Cane and Tepedino (2001) indicate that this variability can depend on various factors including, but not limited to habitat, weather, human activities, and even the time of day one chooses to collect, suggesting the need to study bumble bee biology and seasonality in Alaska. A study on native bee (including *Bombus*) communities in Illinois showed no evidence of a decline in the species composition between late 1800s and 1972 regardless of dramatic changes in land use and agricultural practices throughout the study area (Marlin and LaBerge 2001).

2.4 Alaska Bumble Bees

There is no consensus on the total number of bumble bee species present in Alaska. Bishop and Armbruster (1999) state, but do not list, 18 bumble bee species known from Interior Alaska categorized by sites of various thermal regimes (referring to the amount of heat available for plant growth and development during the growing period). Other authors such as Washburn (1963) suggest up to 22 *Bombus* species. The University of Alaska Museum (UAM 2010) Insect Collection has 28 species of bumble bees from Alaska; however, all species have not been verified yet (D. Sikes, pers. comm.). Table 2.1 includes a compilation of species in Alaska based on literature. Please see Williams (1998) and updated web pages of Williams (1998) checklist at the Natural History Museum (London) *Bombus* database (http://www.nhm.ac.uk/research-curation/research/projects/bombus/index.html) for distribution region descriptions. Table 2.2 identifies eight subgenera of those species listed in Table 2.1. Appendix A lists synonyms and taxonomic notes on selected species listed in Table 2.1.

2.5 *Nosema*

Nosema species is a common microsporidian that has been known to affect a variety of insects including economically important insects such as the silkworm moth, honey bees, and bumble bees (Otti and Schmid-Hempel 2007). Colla et al. (2006) revealed that spillover of pathogens from commercial to wild bumble bees could lead to the transmission of diseases. It has been reported that *Nosema bombi*, that typically infects domesticated bumble bees, has invaded wild native bee colonies (Berenbaum et al. 2007). The cause of recent catastrophic declines throughout North America in native bumble bee colonies such as *B. terricola* Kirby, *B. affinis* Cresson, *B. franklini* Frison, and *B. occidentalis* are likely due to the exposure of this nonnative pathogen (Whittington and Winston 2004; Thorp 2005; Thorp and Shepherd 2005; Evans et al. 2009). It has been proposed that *N. bombi* was spread to wild populations by infected queens that were sent from European rearing facilities in the early 1990's and escaped US greenhouse captivity (Thorp and Shepherd 2005).

Little is known of the biology and transmission of the pathogen between host individuals in native bumble bee colonies, and reports are conflicting on the effects of the pathogen on the host (Schmid-Hempel and Loosli 1998). However, *N. bombi* is an obligate intracellular parasite

that infects differently in different bumble bee species (Otti and Schmid-Hempel 2007). The microsporidian can infect the Malpighian tubules, thorax muscles, fat body tissue, nerve tissue, midgut, and the muscle tissue surrounding the gut epithelium (Fries et al. 2001). Under standardized laboratory conditions in early-infected colonies, Otti and Schmid-Hempel (2007) showed that infected males had lower survival and almost no sperm when compared to those uninfected. Infected gynes (future queens) had crippled wings or swollen abdomens and infected colonies appeared dirty possibly due to diarrhea and inefficient cleaning behavior of the infected workers (Otti and Schmid-Hempel 2007). They also found that a higher proportion of workers from infected colonies died compared to the control colonies.

Table 2.1 List of *Bombus* species reported from Alaska.

Species	Author	Dist.*	Literature Records
B. appositus	Cresson	WN	UAM 2010
B. ashtoni	(Cresson)	WN, EN	Washburn 1963; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. balteatus	Dahlbom	A, P, WN, EN	Ashmead 1902; Bequaert 1920; Washburn 1963; Karlstrom and Ball 1969; Milliron 1973; Williams and Batzli 1982; Thorp et al. 1983; Ascher and Pickering 2010; UAM 2010; CNC 2010
B. bifarius	Cresson	WN	Wasburn 1963; Thorp et al. 1983; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. borealis	Kirby	WN, EN	UAM 2010
B. californicus	Smith	WN, EN, SN	Bequaert 1920; Milliron 1973; Ascher and Pickering 2010; UAM 2010
B. centralis	Cresson	WN	Washburn 1963; Thorp et al. 1983; UAM 2010
B. distinguendus	Morawitz	P	Williams and Thomas 2005; Ascher and Pickering 2010; UAM 2010
B. fernaldae	Franklin	WN, EN	Ashmead 1902; Washburn 1963; Thorp et al. 1983; Guinn 1991; CNC 2010; UAM 2010
B. flavifrons	Cresson	WN	Ashmead 1902; Bequaert 1920; Washburn 1963; Thorp et al. 1983; Guinn 1991; Bishop 1992; Henrich and Vogt 1993; Bishop and Armbruster 1999; Davis 2002; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. frigidus	Smith	WN, WN, A	Ashmead 1902; Bequaert 1920; Washburn 1963; Guinn 1991; Bishop 1992; Henrich and Vogt 1993; Bishop and Armbruster 1999; Davis 2002; Ascher and Pickering 2010; CNC 2010; UAM 2010

* Distribution codes based on Williams (1998): EA = East Nearctic Region, WN = West Nearctic Region, SN = South Nearctic Region, P = Palaearctic, A= Arctic

Table 2.1 Continued – List of *Bombus* species reported from Alaska.

Species	Author	Dist.*	Literature Records
B. hyperboreus	Schonherr	A, P, WN	Washburn 1963; Milliron 1973; Williams and Batzli 1982; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. insularis	(Smith)	WN, EN	Bequaert 1920; Washburn 1963; Thorp et al. 1983; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. jonellus	Kirby	P, A, WN	Ashmead 1902; Washburn 1963; Bishop 1992; Bishop and Armbruster 1999; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. melanopygus	Nylander	WN	Ashmead 1902; Bequaert 1920; Washburn 1963; Thorp et al. 1983; Guinn 1991; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. mixtus	Cresson	WN	Ashmead 1902; Bequaert 1920; Washburn 1963; Thorp et al. 1983; Bishop 1992; Bishop and Armbruster 1999; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. moderatus	Cresson	A, P, WN	Ashmead 1902; Bequaert 1920; Washburn 1963; Milliron 1971; Williams and Batzli 1982; Davis 2002; Ascher and Pickering 2010; UAM 2010
B. neoboreus	Sladen	A, WN	Ashmead 1902; Washburn 1963; Milliron 1973; Williams and Batzli 1982; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. nevadensis	Cresson	WN, EN	Ashmead 1902; Thorp et al. 1983; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. occidentalis	Greene	WN, EN	Ashmead 1902; Bequaert 1920; Wasburn 1963; Thorp et al. 1983; Guinn 1991; Bishop 1992; Bishop and Armbruster 1999; Milliron 1971; Ascher and Pickering 2010; CNC 2010; UAM 2010

* Distribution codes based on Williams (1998): EA = East Nearctic Region, WN = West Nearctic Region, SN = South Nearctic Region, P = Palaearctic, A= Arctic

Table 2.1 Continued – List of *Bombus* species reported from Alaska.

Species	Author	Dist.*	Literature Records
B. perplexus	Cresson	WN, EN	Washburn 1963; Ascher and Pickering 2010; UAM 2010
B. polaris	Curtis	A, P, WN	Ashmead 1902; Washburn 1963; Milliron 1973; Williams and Batzli 1982; Henrich and Vogt 1993; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. rufocinctus	Cresson	WN, EN, SN	Washburn 1963; UAM 2010
B. sandersoni	Franklin	EN	UAM 2010
B. sitkensis	Nylander	WN	Ashmead 1902; Bequaert 1920; Washburn 1963; Thorp et al. 1983; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. suckleyi	(Greene)	WN, EN	Washburn 1963; Karlstrom and Ball 1969; Thorp et al. 1983; Ascher and Pickering 2010; UAM 2010
B. sylvicola	Kirby	A, WN	Bequaert 1920; Washburn 1963; Thorp et al. 1983; Bishop 1992; Henrich and Vogt 1993; Bishop and Armbruster 1999; Davis 2002; Ascher and Pickering 2010; CNC 2010; UAM 2010
B. vagans	Smith	WN, EN	Washburn 1963; UAM 2010

* Distribution codes based on Williams (1998): EA = East Nearctic Region, WN = West Nearctic Region, SN = South Nearctic Region, P = Palaearctic, A= Arctic

Table 2.2 Habitat, food plants, and nesting behavior for bumble bees reported from Alaska.

Subgenus	*Species*	Habitat	Food Plants	Nesting Behavior
Alpinobombus	*B. balteatus,* *B. hyperboreus,* *B. neoboreus,* *B. polaris*	grasslands and shrublands in high arctic and alpine areas	medium to long tongue-length	underground or on the surface
Bombias	*B. nevadensis*	open grassland and mountain meadow	medium to long tongue-length	underground or on the surface
Bombus	*B. moderatus,* *B. occidentalis*	forest edge, mountain meadow, and grassland	short tongue-length; frequently bite holes in corollas and rob deep flowers	underground
Cullumanobombus	*B. rufocinctus*	high alpine grasslands, mountain meadow, and semi-desert	short to medium tongue-length	underground or on the surface
Pyrobombus	*B. bifarius,* *B. centralis,* *B. flavifrons,* *B. frigidus,* *B. jonellus,* *B. melanopygus,* *B. mixtus,* *B. perplexus,* *B. sandersoni,* *B. sitkensis,* *B. sylvicola,* *B. vagans*	mountain-meadow, forest-grassland, semi-desert, and tropical montane forest areas	short to medium tongue-length; workers tend to visit flowers where they have to hang upside down due to their small body sizes	underground or on the surface

Adapted from Williams (1998)

Table 2.2 Continued - Habitat, food plants, and nesting behavior for bumble bees reported from Alaska.

Subgenus	*Species*	Habitat	Food Plants	Nesting Behavior
Psithyrus	*B. ashtoni,* *B. fernaldae,* *B. insularis,* *B. suckleyi*	mountain meadows, forest edges and grassland	short to medium tongue-length; females lack corbiculae on their hind legs	obligate social parasites ("cuckoos") in colonies of other social *Bombus*; therefore, no worker caste
Subterraneobombus	*B. appositus,* *B. borealis,* *B. distinguendus*	alpine grassland, open grassland, and semi-desert	long tongue-length	underground or on the surface
Thoracobombus	*B. californicus*	open grassland, mountain meadow, semi-desert, and tropical montane and lowland forests, less often in temperate forests	medium to long tongue-length	nests on the surface, sometimes underground

Adapted from Williams (1998)

CHAPTER 3. MATERIALS AND METHODS

3.1 Species Composition and Population Dynamics

The three major agricultural areas of Alaska (Benz et al. 2009) were sampled in 2009 and 2010 to include one farm per site near the University of Alaska Fairbanks experimental farms: Delta Junction (N64.04, W145.73), Fairbanks (N64.85, W147.85), and Palmer (N61.60, W149.13), Alaska. Table 3.1 has the summer's average maximum temperatures, cumulative precipitation and cumulative growing degree days from May through September 2009 and 2010 (B. Van Veldhuizen, unpublished data, pers. comm.). Habitat types surrounding the field sites ranged from urban areas with mixed boreal forest near Fairbanks, grasslands and boreal forest near Delta Junction, and large scale commercial agricultural lands near urban areas near Palmer. All three locations grow barley, wheat, oats, and oilseeds such as camelina, canola and mustard (B. Van Veldhuizen, pers. comm.). In Palmer, traps were located near a field of *Rheum* species and within a kilometer from a large potato field.

Table 3.1 Climatic data for the three study sites.

Parameter	Delta Junction		Fairbanks		Palmer	
	2009	2010	2009	2010	2009	2010
Avg Max Temp (°C)	7.45	17.31	18.96	19.47	6.47	16.66
Precipitation (mm)	186.94	220.98	162.56	212.09	138.94	198.37
Cumulative GGD*	1875.60	1925.60	1928.90	2003.10	1835.00	1814.20

* Growing Degree Days = Cumulative (May - September) average daily temperature minus 0°C

Blue vane Japanese beetle traps (SpingStar Inc; Woodinville, Washington) were placed (n=five traps per site per year) around agricultural field perimeters and set at a height of one meter from ground level (Stephen and Rao 2005); however, the traps were hung horizontally to prevent rain from entering. Both years, the traps were placed along a tree or fence line 200 meters apart in a straight line along the same field edge. Traps had a 6.5 cm^2 piece of VAPORTAPE® (Hercon Environmental; Emigsville, Pennsylvania) in the bucket to kill captured insects. The vaportape was replaced every 6 weeks. Traps were serviced every seven days; bumble bees were removed, transported to the laboratory, and stored in labeled Ziploc® bags, and frozen until they could be pinned, labeled and identified in the Agricultural Research Service (ARS) laboratory. Sampling dates were May 19 to September 10, 2009 and March 27 to

September 28, 2010 in Delta Junction; March 27 to September 23, 2009 and May 3 to September 27, 2010 in Fairbanks; May 4 to September 21, 2009 and May 17 to October 7, 2010 in Palmer.

Initially, a series of Alaskan specimens were identified by Dr. Jamie Strange, United States Department of Agriculture Agricultural Research Service, Pollinating Insects Research Unit, Logan, Utah. Subsequent identifications were made using the keys of Thorp et al. (1983) and Stephen (1957) as well as comparison to the voucher collection identified by Strange. Two species, *B. ashtoni* (Cresson) and *B. suckleyi* (Green), were indistinguishable from one another and were lumped together as *B. ashtoni*. Females were identified by the following morphological characteristics: six visible abdominal segments called tergites (T); stinger present; antennae with 10 flagellomeres (segments); mandibles wide and scoop-like. Males were identified by the following morphological characteristics: seven visible tergites with the tip of the abdomen blunt; stinger absent; antennae with 11 flagellomeres; mandibles narrow and bearded. Specimens are currently deposited in the USDA ARS, Subarctic Agricultural Research Unit Insect Collection in Fairbanks, Alaska and will be transferred to UAM upon publication of this work and will be available on the UAM online database.

Five traps were deployed in each site in a completely random design. Each trap was considered a replicate with repeated measurements over time (each week). The data were transformed by square root (capture + 0.5) before analysis (Pantoja et al. 2009, 2010). Significant differences between years, species, and sites were determined at the $P< 0.05$ level using PROC GLM (General Linear Models) (SAS 2008). The three most abundant species at each location were compared. The mean number of bumble bee individuals per trap per seven day period was calculated by combining captures per site, per species, and dates.

3.2 Bumble Bee Pathogens and Parasites

To establish the presence of entomopathogens in bumble bees, ten bees per week were hand collected from the University of Alaska Fairbanks Georgeson Botanical Garden, Fairbanks, Alaska and frozen until their abdomens were dissected following the procedure described by Klee et al. (2006) and Plischuk et al. (2009). Bumble bees were collected with the aid of a glass jar. Only bees resting on flowers or structures were collected. Sampling dates were May 26 to September 17, 2010. Dissected digestive/reproductive tracts were homogenized in 2 ml of

distilled water and the homogenate examined by light microscopy (400X magnification) to determine the presence of microsporidian-like spores of *Nosema* (Klee et al. 2006 and Plischuk et al. 2009).

Nematodes were observed while looking for *Nosema*. The nematodes were placed on baby food plates for nematodes according to Stock et al. (2001). Nematodes were identified by Patricia Stock, University of Arizona Department of Entomology. The percentage of bumble bees infested by *Nosema*-like spores and nematodes were calculated.

3.3 Bumble Bee Key

A key was developed to enable identification of common bumble bee species in Interior Alaska. The key was based on hair color at the vertex (looks like widow's peak), antennal bases (frons), thorax (including the interalar band that is on the top of the thorax between the wing bases), and the hair color pattern on the abdominal segments. Other distinguishing characteristics tend to be difficult to describe and thus hard to observe. The key was designed as public outreach to facilitate identification of the great majority of Alaskan bumble bees; however reference to experts or other sources, is encouraged for accuracy.

The most common color pattern observed from Alaskan collected specimens was used in the guide, but possible variations in color pattern that occurred within a species are noted in Appendix B which also outlines each species' color pattern for the frons, vertex, thorax, and abdominal segments. Guides referenced include keys by Thorp et al. (1983), Stephen (1957), Williams (1998) and Ascher and Pickering (2010) as well as comparison to the voucher collection identified by Jamie Strange, United States Department of Agriculture Agricultural Research Service, Pollinating Insects Research Unit, Logan, Utah. The color diagrams were created in Microsoft Powerpoint. The key was well received by those who were asked to validate it. The key was validated by both those who have identified bumble bees before (2) and those who have never looked closely at a bee (4). For each issue raised by the testers, edits were made within the key.

CHAPTER 4. RESULTS

4.1 Species Composition and Population Dynamics

A total of 8,482 *Bombus* specimens representing 17 species and 6 subgenera were collected in 2009 (66.8%) and 2010 (33.2%) between the months of May and September (Tables 4.2-4.4). Of the 8,482 specimens, 51.0% were queens, 32.7% were workers, and 16.2% were males. The location with the highest relative abundance of bumble bees was Delta Junction with 4,283 specimens representing 50.5% of the overall specimens collected. The other two locations, Fairbanks and Palmer represented 25.8% and 23.5% of the overall insect catch respectively.

The overall statistical analysis (SAS 2008) indicate significant differences (P>0.0001) between years, species, and sites, location by species, and year by species requiring individual analysis by site, year, and species (Table 4.1). Tables 4.2 through 4.4 are a list of identified bumble bee species collected with blue vane traps segregated by site (Delta Junction, Fairbanks, and Palmer), species, and year.

Table 4.1 ANOVA Table.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
replication	5	34.23	6.84	41.12	< 0.0001
location	2	24.11	12.06	72.41	< 0.0001
year	1	25.01	25.01	150.24	< 0.0001
species	16	71.37	4.46	26.79	< 0.0001
year x species	16	18.58	1.16	6.98	< 0.0001
location x species	32	121.23	3.79	22.75	< 0.0001

4.1.1 Delta Junction

There were 15 species (Table 4.2) in Delta Junction: *B. ashtoni*, *B. balteatus* Dahlbom, *B. bifarius* Cresson, *B. centralis* Cresson, *B. fernaldae* Franklin, *B. frigidus* Smith, *B. insularis* (Smith), *B. jonellus* Kirby, *B. melanopygus* (Nylander), *B. mixtus* Cresson, *B. moderatus* Cresson, *B. occidentalis*, *B. perplexus* Cresson, *B. rufocinctus* Cresson, *B. sylvicola* Kirby. The most abundant species both years was *B. bifarius* representing approximately 46% and 54% of the specimens collected in 2009 and 2010 respectively. *Bombus bifarius* queens, workers, and males were the

most abundant in 2010. In 2009, *Bombus bifarius* queens and workers were most abundant, but *B. jonellus* male counts were almost equal to *B. bifarius*. All 15 species were collected each year.

In 2009, three species, *B. bifarius* (46.3%), *B. jonellus* (17.1%), and *B. frigidus* (11.0%) represented 74% of the total bumble bees collected. In 2010, a different set of species, *B. bifarius*, *B. occidentalis*, and *B. jonellus,* contributed 76.4% of the specimens that year with percentages of 54.1, 12.4, and 9.9 respectively. *Bombus bifarius* was the only species in high numbers during both years. In 2009, 2,469 specimens were collected, of those 48.1% were queens, 38.6% were workers, and 13.3% were males. Insect relative abundances were lower in 2010 as compared to 2009; however, the percentage of queens was higher in 2010 (79.1%) as compared to 2009 (48.1%).

Flight activity, represented by the mean number of bumble bees per trap per seven day sampling interval during 2009 is presented in Figure 4.1. Flight activity started in early May with a mean of 80.6 for *B. bifarius* per trap per seven days. This species displayed the highest relative insect abundance on this site and year. A second, but lower peak of activity, with a mean of 65.2 bees per trap per seven days was recorded in mid-June. No flight activity by any species was detected after September 14. *Bombus frigidus* displayed a population peak on June 30 with a mean of 34.6 bees per trap per seven days and leveled off late July. *Bombus jonellus* displayed a peak on June 30 with a mean of 54.8 bees per seven days then leveling off in late July.

Similar to the 2009 season, *B. bifarius* was the most abundant species in 2010 (Figure 4.2). However, *B. frigidus* was collected in lower relative abundance (6.1%) in 2010 as compared to 2009 (11%). On the other hand, *B. occidentalis* was among the most prevalent species (Figure 4.2) in 2010. *Bombus bifarius* relative abundances in 2009 were almost double to those in 2010; displaying a peak May 14 with a mean of 27.2 bees per trap per seven days and then again in late August with a mean of 2.2, no activity was detected after September 7. *Bombus jonellus* displayed a peak on May 21 with a mean of 6.4 then leveling off in late July. *Bombus occidentalis* displayed a peak on May 30 with a mean of 10.5 bees per trap per seven day period followed by a small peak in July then no activity past August 7. Contrary to 2009, a large peak in activity was seen from the beginning of May until the second week of June during this year's field season compared to the later peak in mid-June to the beginning of July that was seen in 2009. No flight activity was detected for any species after the first week of September.

Table 4.2 Sum of queens (Q), workers (W), males (M) ± standard error, and percentage of overall bumble bees collected with blue vane traps near Delta Junction, Alaska 2009-2010.

species	Author	2009				2010			
		Q	W	M	%	Q	W	M	%
B. ashtoni	(Cresson)	16 ± 0.05	0	0	0.6	2 ± 0.01	0	0	0.1
B. balteatus	Dahlbom	4 ± 0.02	1 ± 0.01	0	0.2	3 ± 0.01	0	0	0.2
B. bifarius	Cresson	739 ± 2.70	315 ± 2.10	90 ± 0.5	46.3	794 ± 0.80	138 ± 0.15	49 ± 0.07	54.1
B. centralis	Cresson	37 ± 0.14	5 ± 0.03	10 ± 0.05	2.1	46 ± 0.06	12 ± 0.02	9 ± 0.02	3.7
B. fernaldae	Franklin	7 ± 0.03	0	0	0.3	4 ± 0.01	0	1 ± 0.00	0.3
B. frigidus	Smith	52 ± 0.22	171 ± 0.76	49 ± 0.25	11.0	94 ± 0.13	13 ± 0.02	4 ± 0.01	6.1
B. insularis	(Smith)	52 ± 0.13	0	0	2.1	34 ± 0.05	0	0	1.9
B. jonellus	Kirby	55 ± 0.24	276 ± 1.16	91 ± 0.40	17.1	144 ± 0.20	36 ± 0.06	0	9.9
B. melanopygus	Nylander	12 ± 0.06	60 ± 0.28	47 ± 0.34	4.8	57 ± 0.09	5 ± 0.01	3 ± 0.01	3.6
B. mixtus	Cresson	101 ± 0.36	30 ± 0.13	3 ± 0.02	5.4	73 ± 0.08	2 ± 0.01	0	4.1
B. moderatus	Cresson	1 ± 0.12	1 ± 0.12	0	0.1	9 ± 0.02	2 ± 0.01	0	0.6
B. occidentalis	Greene	70 ± 0.29	57 ± 0.22	0	5.1	143 ± 0.21	79 ± 0.08	2 ± 0.01	12.4
B. perplexus	Cresson	17 ± 0.09	7 ± 0.03	2 ± 0.02	1.1	24 ± 0.03	3 ± 0.01	6 ± 0.02	1.8
B. rufocinctus	Cresson	9 ± 0.04	0	0	0.4	1 ± 0.00	1 ± 0.00	0	0.1
B. sylvicola	Kirby	15 ± 0.06	31 ± 0.15	36 ± 0.20	3.3	8 ± 0.15	2 ± 0.01	11 ± 0.03	1.2
TOTAL		**1187**	**954**	**328**		**1436**	**293**	**85**	

SUM 2009 = 2,469

SUM 2010 = 1,814

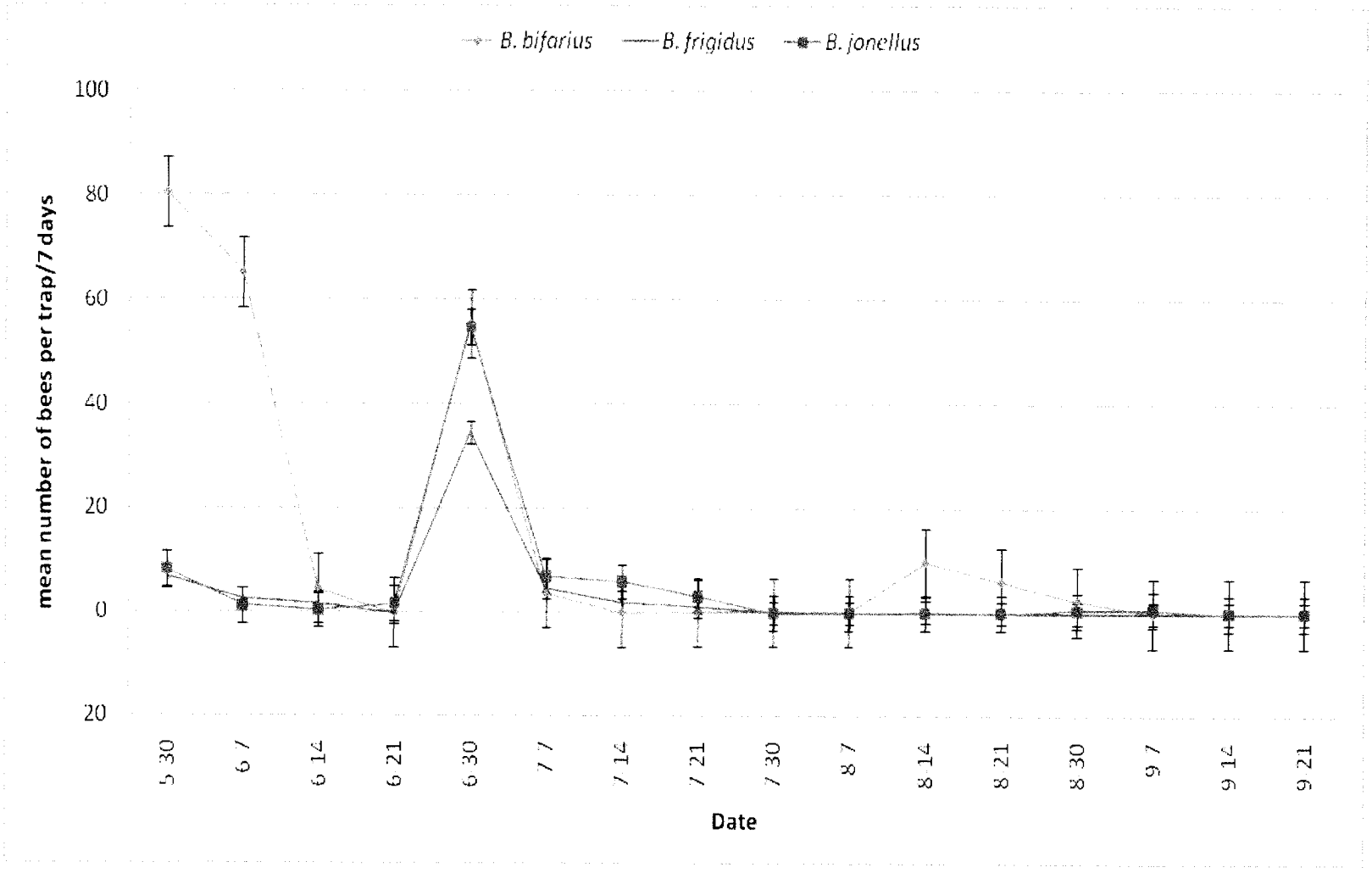

Figure 4.1 Mean number and standard errors of *B. bifarius*, *B. frigidus*, and *B. jonellus* per trap per 7 day sampling period collected with blue vane traps near Delta Junction, Alaska 2009.

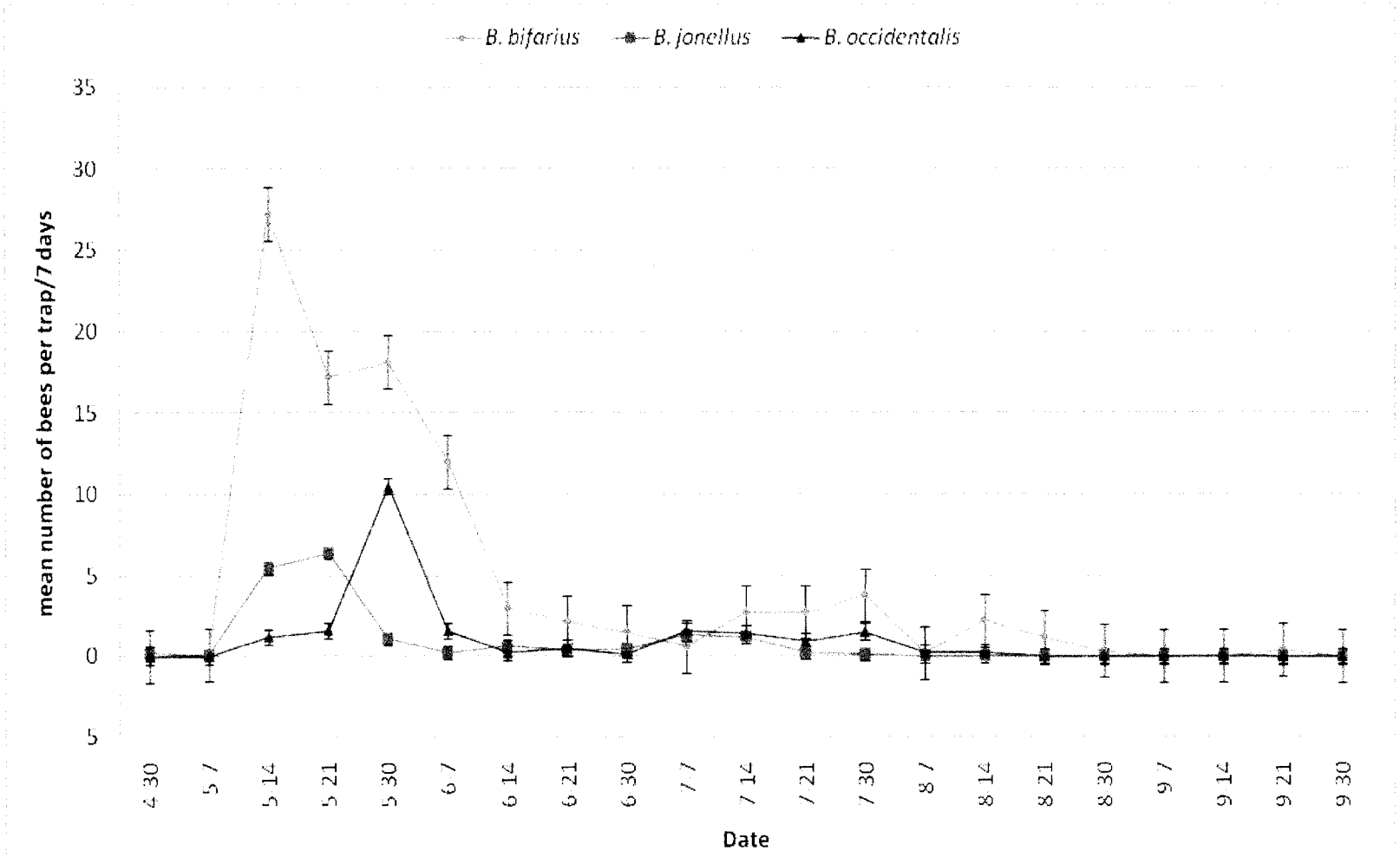

Figure 4.2 Mean number and standard errors of *B. bifarius*, *B. jonellus*, and *B. occidentalis* per trap per 7 day sampling period collected with blue vane traps near Delta Junction, Alaska 2010.

4.1.2 Fairbanks

In 2009, 2,134 specimens were collected representing 96% of the total number of specimens collected at the Fairbanks site during both years. During 2010, a total of 57 specimens were collected representing 2.6% of the specimens for the locality. The total number of bumble bee species in Fairbanks (Table 4.3) was equal to that in Delta Junction (Table 4.2) - both with 15 species. However the species composition was different between Delta Junction and Fairbanks. The following species were collected from Fairbanks: *B. bifarius*, *B. borealis* Kirby, *B. centralis*, *B. fernaldae*, *B. flavifrons*, *B. frigidus*, *B. insularis*, *B. jonellus*, *B. melanopygus*, *B. mixtus*, *B. moderatus*, *B. occidentalis*, *B. perplexus*, *B. rufocinctus*, and *B. sylvicola*. In Fairbanks, *B. ashtoni* and *B. balteatus* were not collected, but in Delta Junction, they were.

Additionally, the species composition varied between years in the Fairbanks site with fourteen species collected in 2009 and only eight during 2010. *Bombus sylvicola* was collected in low numbers in 2009 and was not collected in 2010 at this locality (Table 4.3). The most abundant species both years was *B. jonellus* representing approximately 30% and 42% of the specimens collected in 2009 and 2010 respectively at the Fairbanks site.

In 2009, three species contributed 69.9% of the specimens to include: *B. jonellus*, *B. perplexus*, and *B. occidentalis* with percentages of 29.9, 26.5, and 13.5 respectively (Figure 4.3). In 2010, three species contributed 82.5% of the specimens that year: *B. jonellus*, *B. centralis*, and *B. perplexus* with percentages of 42.1, 28.1, and 12.3, respectively (Figure 4.4).

The three most prevalent species for 2009 were *B. jonellus*, *B. occidentalis*, and *B. perplexus* (Figure 4.3). *Bombus jonellus* displayed the highest insect relative abundance on this site and year with a mean of 54.6 bees per trap per seven days around June 30. Neither *B. perplexus* nor B. *jonellus* were collected after July 21; however *B. occidentalis* displayed flight activity until July 30. *Bombus perplexus* displayed a peak in late May, again in late June then no activity was detected after July 21. All flight activity ended in August.

Table 4.3 Sum of queens (Q), workers (W), males (M) ± standard error, and percentage of overall bumble bees collected with blue vane traps near Fairbanks, Alaska 2009-2010.

species	Author	2009				2010			
		Q	W	M	%	Q	W	M	%
B. bifarius	Cresson	0	0	0	0.0	0	1 ± 0.00	0	1.8
B. borealis	Kirby	0	3 ± 0.02	0	0.1	0	0	0	0.0
B. centralis	Cresson	170 ± 0.68	27 ± 0.12	3 ± 0.02	9.4	5 ± 0.02	8 ± 0.02	3 ± 0.01	28.1
B. fernaldae	Franklin	0	0	2 ± 0.01	0.1	0	0	0	0.0
B. flavifrons	Cresson	0	0	3 ± 0.02	0.1	0	0	0	0.0
B. frigidus	Smith	74 ± 0.19	58 ± 0.15	34 ± 0.10	7.8	1 ± 0.00	0	0	1.8
B. insularis	(Smith)	11 ± 0.05	0	2 ± 0.01	0.6	0	0	0	0.0
B. jonellus	Kirby	94 ± 0.26	328 ± 0.86	217 ± 0.64	29.9	21 ± 0.05	3 ± 0.01	0	42.1
B. melanopygus	Nylander	79 ± 0.23	110 ± 0.33	33 ± 0.10	10.4	1 ± 0.00	0	0	1.8
B. mixtus	Cresson	20 ± 0.08	0	0	0.9	2 ± 0.01	0	0	3.5
B. moderatus	Cresson	0	9 ± 0.03	0	0.4	0	0	0	0.0
B. occidentalis	Greene	42 ± 0.12	246 ± 0.58	0	13.5	4 ± 0.01	1 ± 0.00	0	8.8
B. perplexus	Cresson	253 ± 0.63	306 ± 0.81	6 ± 0.03	26.5	6 ± 0.02	1 ± 0.00	0	12.3
B. rufocinctus	Cresson	1 ± 0.01	0	0	0.1	0	0	0	0.0
B. sylvicola	Kirby	1 ± 0.01	1 ± 0.01	1 ± 0.01	0.1	0	0	0	0.0
TOTAL		**745**	**1088**	**301**		**40**	**14**	**3**	

SUM 2009 = 2,134

SUM 2010 = 57

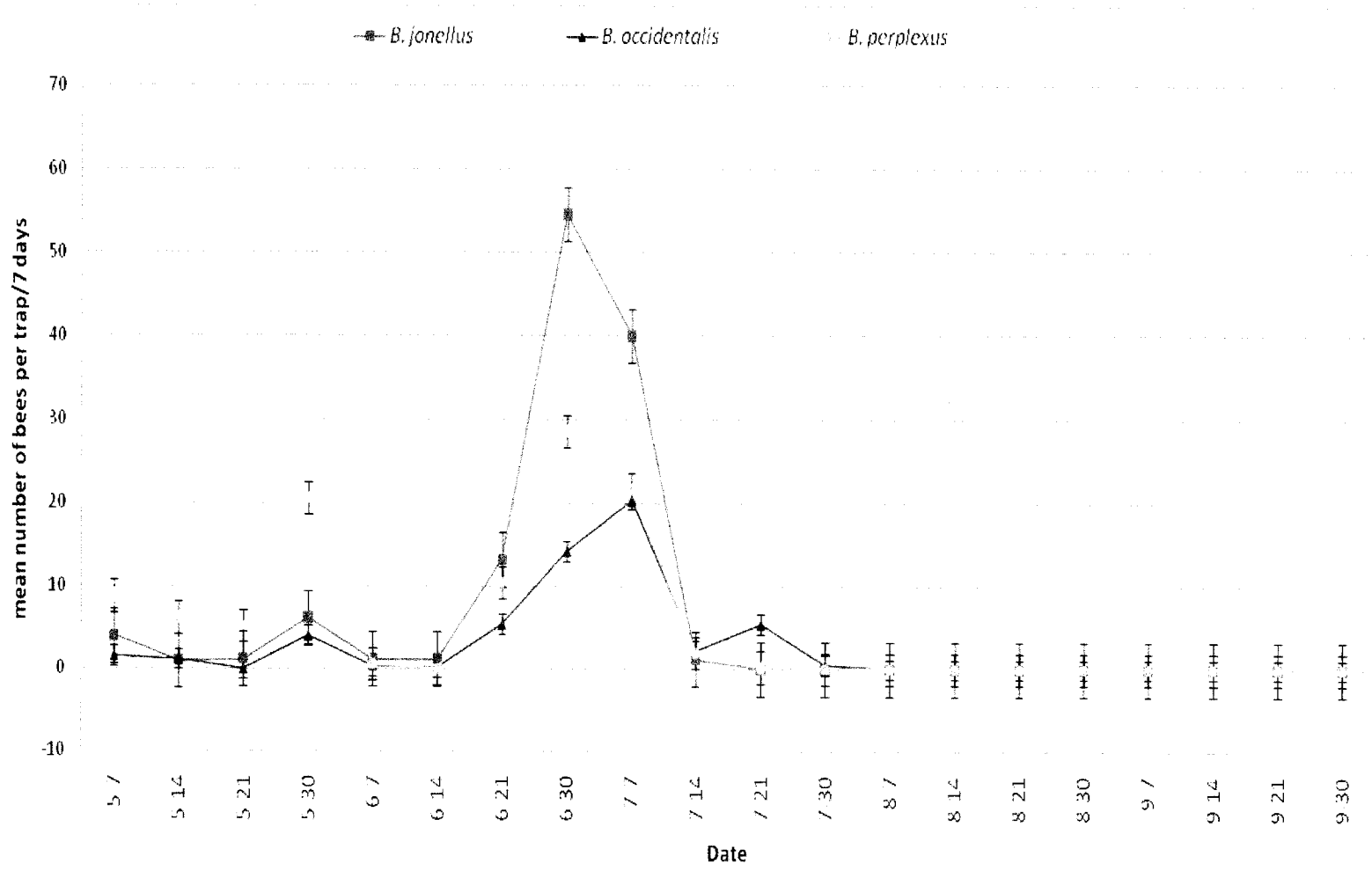

Figure 4.3 Mean number and standard errors of *B. jonellus*, *B. occidentalis*, and *B. perplexus* per trap per 7 day sampling period collected with blue vane traps near Fairbanks, Alaska 2009.

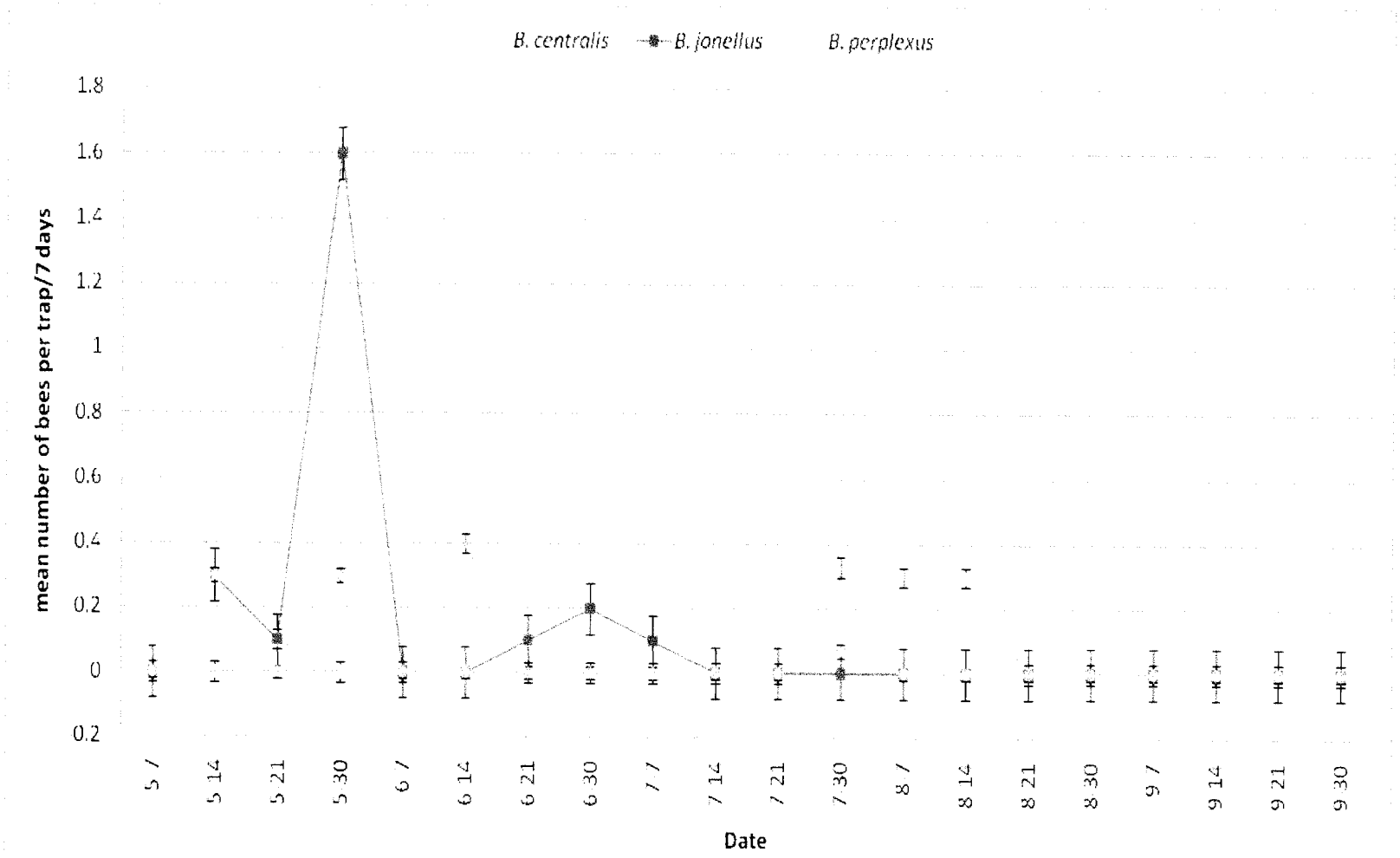

Figure 4.4 Mean number and standard errors of *B. centralis*, *B. jonellus*, and *B. perplexus* per trap per 7 day sampling period collected with blue vane traps near Fairbanks, Alaska 2010.

Flight activity was earlier in 2010 (Figure 4.4) than in 2009 (Figure 4.3). The prevalent three species were the same in both years, but their relative abundances varied between years. *Bombus jonellus* was the most abundant species in both years (Figures 4.3 and 4.4), but reached maximum numbers at different times each year. In 2009, *B. jonellus* reached maximum at the end of June with a mean of 54.6 insects per trap per seven day period. In 2010, *B. jonellus* reached its maximum relative abundance at the end of May with a mean of 1.6 bees per trap per seven days. *Bombus centralis* displayed a peak in June and then again in late July, displaying no activity past August 21. *Bombus perplexus* displayed a peak in early May, again in late July then no activity was detected past August 7. All flight activity ended in mid-August compared to 2009 when activity ceased at the beginning of August.

4.1.3 Palmer

Species richness in Palmer (Table 4.4) was lower (14 species total) than in Delta Junction (Table 4.2) and Fairbanks which had 15 species (Table 4.3). Not all species were present both years; *B. sylvicola* was collected in low numbers in 2009 and was not recovered in 2010 (Table 4.4). The other difference in species composition between years was that *B. bifarius* was collected in low numbers in 2010, but not collected during the 2009 season (Table 4.4). The most abundant species both years was *B. centralis* representing 39.1% and 37.2% for 2009 and 2010 respectively. The three most prevalent species in 2009 (Figure 4.5) and 2010 (Figure 4.6) were *B. centralis*, *B. flavifrons*, and *B. occidentalis.*

In 2009, three species, *B. centralis*, *B. flavifrons*, and *B. occidentalis*, contributed 71.5% of the specimens with percentages of 39.1, 19.6, and 12.8 respectively. In 2010 the same three species contributed 69.1% of the specimens that year, but the relative abundance was different than in 2009 with percentages of 37.2, 23.2, and 8.7 for *B. centralis*, *B. flavifrons*, and *B. occidentalis,* respectively.

In 2009, *B. centralis* and *B. flavifrons* were collected as early as 14 May; while *B. occidentalis* displayed activity during the first week sampled (Figure 4.5). *Bombus centralis* displayed four peaks at different relative densities: one on May 30 (with a mean of 12.4), June 14 (with a mean of 18.4 bees per trap per seven days), August 7 (with a mean of 17.6 bees per trap per seven days) and September 7 (with a mean of 10.8 bees per trap per seven days) before activity ceased altogether.

Table 4.4 Sum of queens (Q), workers (W), males (M) ± standard error, and percentage of overall bumble bees collected with blue vane traps near Palmer, Alaska 2009-2010.

species	Author	2009				2010			
		Q	W	M	%	Q	W	M	%
B. ashtoni	(Cresson)	17 ± 0.06	0	6 ± 0.04	2.2	54 ± 0.19	0	0	5.7
B. balteatus	Dahlbom	1 ± 0.01	0	0	0.1	0	2 ± 0.01	0	0.2
B. bifarius	Cresson	0	0	0	0.0	1 ± 0.01	0	0	0.1
B. centralis	Cresson	227 ± 0.58	49 ± 0.14	140 ± 0.52	39.1	37 ± 0.08	189 ± 0.50	126 ± 0.29	37.2
B. fernaldae	Franklin	16 ± 0.6	0	3 ± 0.02	1.8	55 ± 0.19	0	0	5.8
B. flavifrons	Cresson	52 ± 0.15	15 ± 0.05	141 ± 0.51	19.6	14 ± 0.04	65 ± 0.21	140 ± 0.33	23.2
B. frigidus	Smith	28 ± 0.10	5 ± 0.03	2 ± 0.02	3.3	11 ± 0.04	3 ± 0.01	0	1.5
B. insularis	(Smith)	22 ± 0.08	0	4 ± 0.03	2.5	63 ± 0.25	0	0	6.7
B. jonellus	Kirby	25 ± 0.07	4 ± 0.02	1 ± 0.01	2.8	32 ± 0.15	0	1 ± 0.01	3.5
B. melanopygus	Nylander	85 ± 0.30	5 ± 0.03	1 ± 0.01	8.6	2 ± 0.01	5 ± 0.02	0	0.7
B. mixtus	Cresson	61 ± 0.20	10 ± 0.06	0	6.7	59 ± 0.21	1 ± 0.01	1 ± 0.01	6.5
B. moderatus	Cresson	0	0	1 ± 0.01	0.1	2 ± 0.01	0	0	0.2
B. occidentalis	Greene	8 ± 0.05	41 ± 0.11	87 ± 0.52	12.8	42 ± 0.13	33 ± 0.07	7 ± 0.02	8.7
B. sylvicola	Kirby	6 ± 0.03	0	0	0.6	0	0	0	0.0
TOTAL		**548**	**129**	**386**		**372**	**298**	**275**	

SUM 2009 = 1,063

SUM 2010 = 945

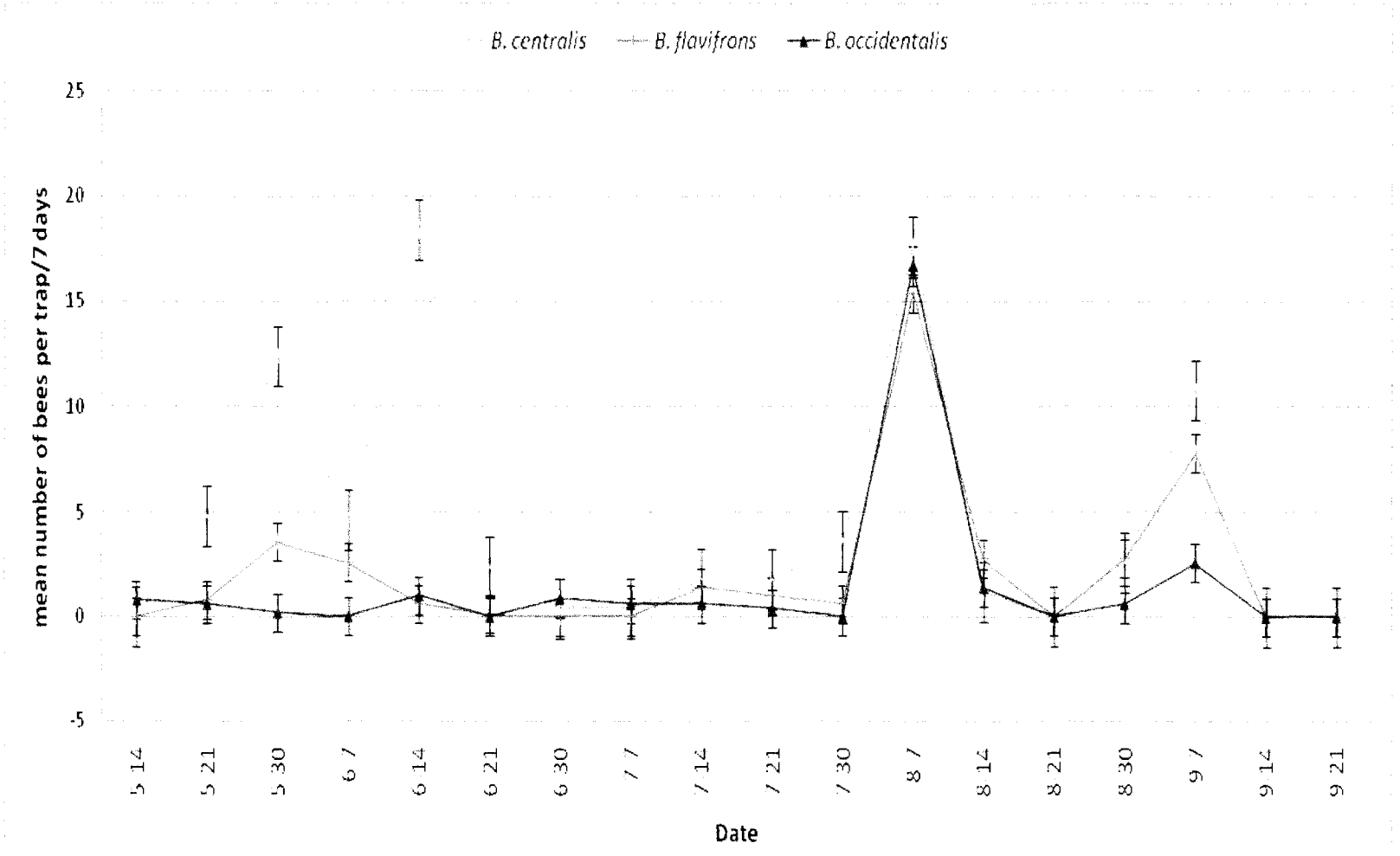

Figure 4.5 Mean number and standard errors of *B. centralis*, *B. flavifrons*, and *B. occidentalis* per trap per 7 day sampling period collected with blue vane traps near Palmer, Alaska 2009.

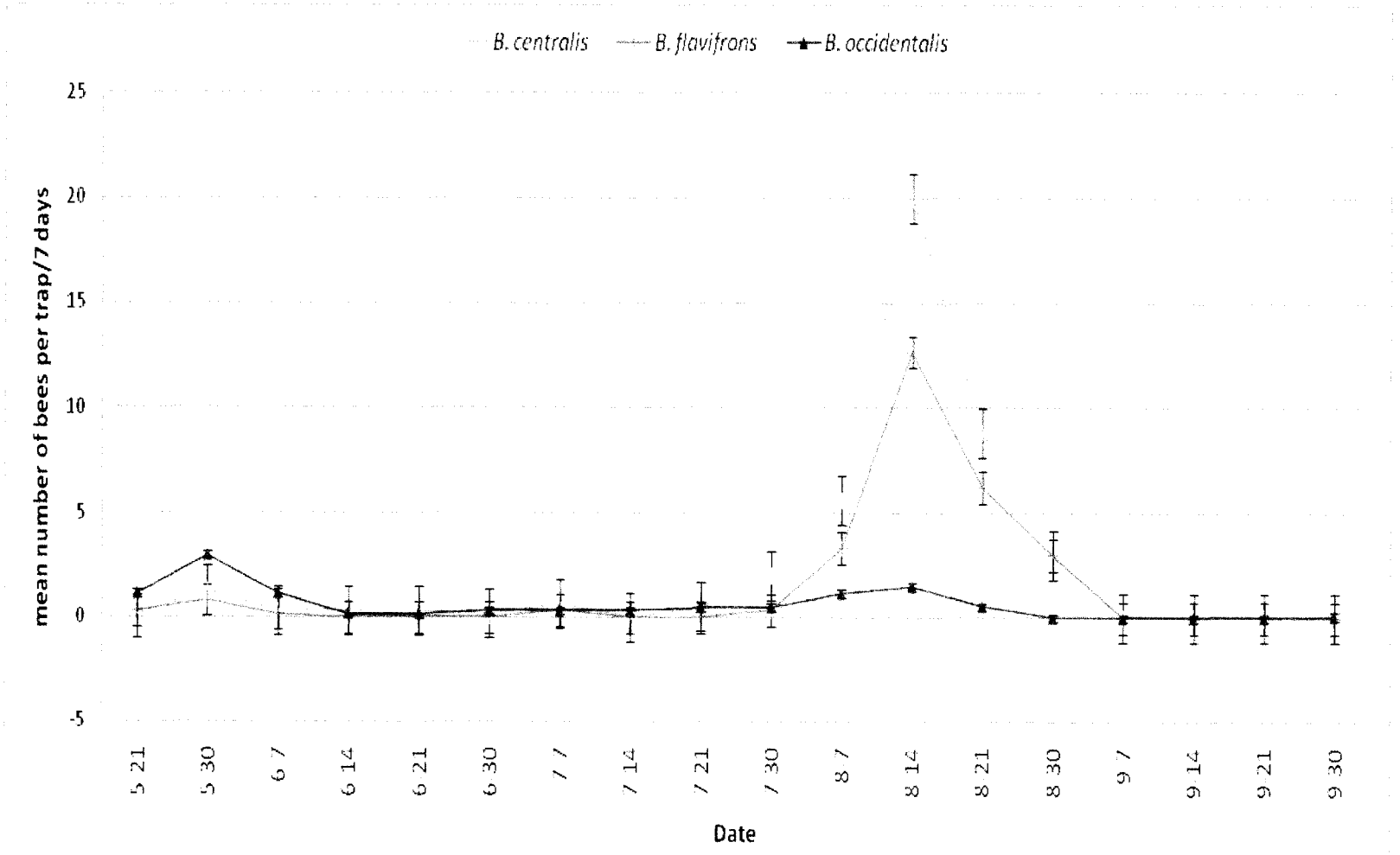

Figure 4.6 Mean number and standard errors of *B. centralis*, *B. flavifrons*, and *B. occidentalis* per trap per 7 day sampling period collected with blue vane traps near Palmer, Alaska 2010.

Bombus flavifrons displayed a peak on May 30 and then again on August 7, followed by another peak on September 7 before no activity was detected. *Bombus occidentalis* displayed a peak on August 7 and September 7 before no activity was detected. All three species displayed a peak at the beginning of August on the seventh, with mean number of bees per trap per seven days of 17.6 (*B. centralis*), 15.4 (*B. flavifrons*), and 16.7 (*B. occidentalis*).

In 2010, all species displayed a small peak in late May then again in mid-August (Figure 4.6). *B. centralis* displayed the highest relative abundance observed at this locality and year by August 15 (a mean of 20 bees per trap per seven days) and no insects of any species were collected after September 7. *Bombus flavifrons* displayed a single peak by August 14. *Bombus occidentalis* displayed a peak in late May and again in mid-August. Contrary to 2009, peak activity during 2010 was towards the end of the season in August. In 2009, activity peaked mid-May, mid-June, early August and again early September (Figure 4.5).

4.2 Bumble Bee Pathogens and Parasites

A total of 101 bumble bee specimens from eight species were examined for microsporidian (*Nosema* spp.) and nematodes (Table 4.5). Out of the 8 species surveyed, *B. centralis* and *B. occidentalis* tested positive for microsporidian while *B. centralis* and *B. perplexus* tested positive for nematodes (Table 4.5). The nematodes were identified as belonging to the family Tetradonematidae. Overall nematode incidence was 16.7% (Table 4.5) as compared to overall microsporidian infestations (12.5%). The highest incidence of microsporidian infection was detected for *B. occidentalis* at 12.5% while the highest nematode incidence was recorded *for B. centralis* at approximately 17%.

Table 4.5 Percentage of *Bombus* species infected with *Nosema* and Nematodes.

species	N	*Nosema*	%	Nematodes	%
B. centralis	48	3	6.3	8	16.7
B. frigidus	1	0	0.0	0	0.0
B. jonellus	2	0	0.0	0	0.0
B. moderatus	1	0	0.0	0	0.0
B. occidentalis	24	3	12.5	0	0.0
B. perplexus	16	0	0.0	1	6.3
B. fernaldae	2	0	0.0	0	0.0
B. insularis	7	0	0.0	0	0.0
TOTAL	101	6		9	

4.3 Bumble Bee Key

See Appendix B for distinguishing features for each species and Figure 4.7 for the color key. Distinguishing features were based on personal observations, personal communication with bee experts and other descriptions by Stephen (1957), Thorp et al. (1983), Williams (1998) and updated web pages of Williams (1998) checklist at the Natural History Museum *Bombus* database (http://www.nhm.ac.uk/research-curation/research/projects/bombus/index.html), as well as Ascher and Pickering (2010) with updated web pages at DiscoverLife.org (http://www.discoverlife.org/mp/20q?guide=Bumblebees).

The key was created for queens and workers (females). The key could be used for male identification, but males can show a higher degree of variability than their female counterparts. Females have six visible abdominal segments called tergites (T); stinger present; antennae with 10 flagellomeres (segments); mandibles are wide and scoop-like. Males have seven visible tergites with the tip of their abdomen blunt; stinger absent; antennae with 11 flagellomeres; mandibles are narrow and bearded.

Key to Queens and Workers of common Interior Alaskan *Bombus*:

1a. Pollen basket present (metatibia concave and shiny or with pollen ball); some hair on T1-T2 (subgenus *Bombus*)..... 2

1b. Pollen basket not present (metatibia convex and opaque); bald or black hairs on T1-T2; yellow hair sparse or absent (subgenus *Psithyrus*)..... 5

2a. T1-4 with yellow hair only.....*borealis*

2b. At least some tergites between 1 through 5 with black, orange or white hair..... 3

3a. Bees with rust or orange on any of the abdominal segments..... *frigidus, balteatus, centralis, mixtus, melanopygus, sylvicola, bifarius*

3b. No rust or orange hairs on abdomen..... 4

4a. Most or all of T1 with black hairs (note: double check couplet 1 to confirm unknown is not *Psithyrus*)..... *occidentalis, moderatus*

4b. T1-T2 all or mostly yellow..... *perplexus, jonellus, flavifrons, rufocinctus*

5a. T1-T2 black; T3-T5 yellow hair mostly laterally but not medially; T6 hairless..... *insularis*

5b. T1-T3 mostly black; T3 black or with yellow/blonde hair laterally; T4 yellow or blonde; T5 black with hair laterally; T6 hairless.....*ashtoni, fernaldae*

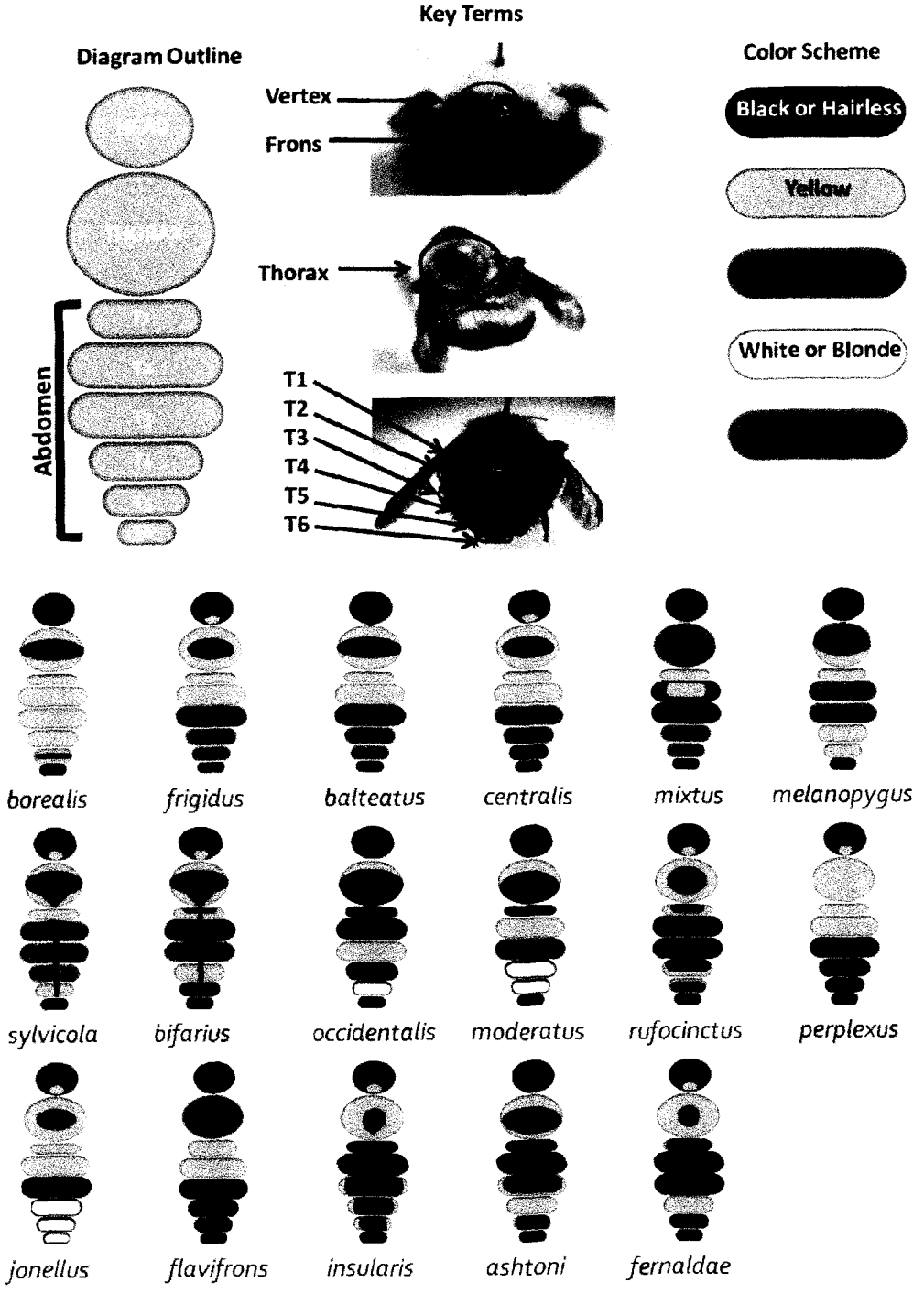

Figure 4.7 Color key to the most common Interior Alaskan bumble bees.

CHAPTER 5. DISCUSSION

Research conducted from 2009 to 2010 in the main agricultural areas of Alaska resulted in the identification of 17 bumble bees species associated with agricultural settings: *B. ashtoni, B. balteatus, B. bifarius, B. borealis, B. centralis, B. fernaldae, B. flavifrons, B. frigidus, B. insularis, B. jonellus, B. melanopygus, B. mixtus, B. moderatus, B. occidentalis, B. perplexus, B. rufocinctus,* and *B. sylvicola.* The species composition and relative insect abundances varied among sites and years. The highest relative insect abundance and species richness was documented in Delta Junction with 50% of the total number of specimens collected both years in the three sites studied. The other two locations, Fairbanks and Palmer represented 25.8% and 23.7% of the overall catch respectively. Fifteen of the identified species were collected from Delta Junction, fourteen from Palmer and fifteen species from the Fairbanks area.

Of the 17 species collected in this field study, six species were found at all three locations during both sampling years: *B. centralis, B. frigidus, B. jonellus, B. melanopygus, B. mixtus,* and *B. occidentalis*. Nine species previously reported in Alaska (Ashmead 1902; Bequaert 1920; Washburn 1963; Milliron 1973; Williams and Batzli 1982; Thorp et al. 1983; Henrich and Vogt 1993; Williams and Thomas 2005; Ascher and Pickering 2010; CNC 2010; UAM 2010), but not collected in the field study include: *B. appositus* Cresson, *B. californicus* Smith, *B. distinguendus* Morawitz, *B. hyperboreus* Schonherr, *B. neoboreus* Sladen, *B. nevadensis* Cresson, *B. polaris* Curtis, *B. sandersoni* Franklin, *B. sitkensis* Nylander. The absence of these nine species from this long term study is possibly associated with the distribution range of the species, but this theory requires additional research and was not in the scope of this study.

The presence of *Bombus suckleyi* in Alaska could not be confirmed from field collections; this species is indistinguishable from *B. ashtoni. Bombus borealis* was not collected from Delta Junction or Palmer; *B. ahtoni* and *B. balteatus* were not collected from Fairbanks; *B. flavifrons* was not collected from Delta Junction; *B. perplexus* and B. *rufocinctus* were not collected from Palmer.

Overall, bumble bee abundances were affected by year and site. The most abundant species collected was *B. bifarius* which was collected in high numbers both years in Delta Junction, but only one specimen was collected from Fairbanks in 2010 and one from Palmer in 2010. The earliest sampling date was March 30; however, depending on sites and years, fight

activity was detected during the first week sampling was initiated, suggesting that flight activity started earlier than May 3. Future studies should initiate sampling by mid-April. No previous reports on flight activity of Alaska bumble bees are available to compare to this study. Davis (2002) reported on bumble bees from lingonberries in Alaska, but did not state the sampling dates.

Relative population abundances were lower in 2010 compared to 2009 (Tables 4.2-4.4). Differences in species richness between localities and species relative abundances between years cannot be easily explained based on the limited knowledge on bumble bee biology in the state. Bumble bee populations and local diversity can be highly variable from year to year depending on various factors including, but not limited to habitat, weather, human activities, and even the time of day one chooses to collect (Cane and Tepedino 2001; Roubik 2001). Time of day was not a factor in this study since the traps were serviced weekly. Further investigation is needed to study the effect of biotic and abiotic factors on bumble bee biology in Alaska.

Bumble bee biology can also be affected by the availability of floral resources and nest sites, climatic conditions, presence of invasive species, habitat fragmentation, parasitic spillover, urbanization, competition, and the use of pesticides (Goulson et al. 2008). The sites studied here have significant climatic differences (Benz et al. 2009) and cropping histories that can affect insect relative densities (Pantoja et al. 2009). The close proximity to the sea maintains Palmer in moderate temperatures and slightly wetter than Fairbanks and Delta.

The subarctic climate in Fairbanks and Delta Junction is drier as result of being much further away from the ocean and provides short, warm summers followed by long, cold winters. It was much warmer in 2010 at all locations than in 2009; however, there was more precipitation in 2010 than in 2009 at all locations. Fewer bumble bees were collected in 2010 than in 2009; climate differences probably affected the populations observed in this study, but this requires additional research.

Traps in Delta Junction were located in rural areas, while traps in Fairbanks and Palmer were within three kilometers from major highways. However, the effects of urbanization and habitat fragmentation were not within the scope of the study and require additional research. Delta Junction observed the highest relative insect abundance. Working with a different group of insects, Pantoja et al. (2009) reported a similar pattern of higher relative densities in

leafhoppers (Cicadellidae) in the Delta Junction areas as compared to Fairbanks and Palmer. Additional research is needed to establish if the differences observed in this study. The report by Pantoja et al. (2009) suggests the differences observed are associated to climatic differences, habitat availability, or agronomic practices.

Depending on the year and site, *B. bifarius*, *B. centralis*, *B. frigidus*, and *B. jonellus* were the predominate species in the three sites. The differences in species prevalence among sites could be explained by plant or crops available at each site. For example, Fairbanks and Palmer include flowers, agricultural crops, and various vegetation in research plots. In contrast, in Delta Junction, the predominate crops at the site included small research plots of barley, wheat, grasses and extensive areas of open space with native vegetation. However, all three locations grow barley, wheat, oats, and oilseeds such as camelina, canola and mustard (B. Van Veldhuizen, pers. comm.). The oilseeds require insect pollination and canola was observed to be the most attractive to bumble bees (B. Van Veldhuizen, pers. comm.). Canola expresses a blooming period from mid-June to mid-August.

Most bumble bee species collected from all three sites belong to the subgenus *Pyrobombus*. Members of this subgenus are characterized by short to medium tongue lengths and workers tend to visit flowers where they have to hang upside down due to their small body sizes. Alaskan plants with hanging or small corollas can include, but are not limited to bluebells, harebells, columbines, and many native berries.

This study did not characterize flower or plant types on the research sites to correlate the findings on bumble bee species richness and flight activity with vegetation growth patterns at each site and year. Perhaps the large, open undisturbed areas in Delta Junction with natural vegetation patches affected bumble bee species density, diversity, and activity as compared to the Fairbanks and Palmer sites. In Fairbanks and Palmer, the soil is frequently disturbed and structures were in close proximity to traps. According to Williams (1986), bumble bee populations near crop fields respond positively where unmanaged lands are set aside in the form of pastures, meadows, and forests. These sorts of areas provide nesting and forage sites for the bees (Williams 1986). Davros et al. (2006) found similar findings with butterflies in that butterfly densities and species are affected by disturbances and habitat fragmentation (Davros et al. 2006). Delta Junction has large areas devoted to Conservation Reserve Program (NRCS

2010). Other factors that could have affected species diversity or density include cropping history (Pantoja et al. 2009), parasites, and vertebrate predator populations.

Davis (2002) mentions *B. terrestris*, *B. flavifrons*, and *B. sylvicola* as potential primary pollinators of lingonberries out of three other *Bombus* species seen visiting lingonberry flowers in Fairbanks. *Bombus flavifrons* was collected in high densities at least in Palmer (Table 4.2). Voucher specimens from Davis (2002) were not available for taxonomical confirmation, but the specimens listed by Davis as *B. terrestris* is probably a misidentification of *B. moderatus* (Appendix A). *Bombus moderatus* and *B. sylvicola* were collected in this study, but made up less than 4% in any location or year.

The highest insect counts observed during the trial were for the locality of Delta Junction during the year 2009 with a mean number of 80.6 bumble bees per trap per seven days. No previous reports from Alaska provide comparative data to put these values in context. In Oregon, Stephen and Rao (2005) mention a capturing average of 17.3 bees per day using the same blue vane trapping methods.

Insect counts in Palmer were consistent between years with a difference of 118 bees between the two years. The most abundant species were the same both years and in roughly the same relative abundance (Table 4.4). During both years, traps were hung in close proximity to *Rheum* that provided a consistent foraging source during both years. Information on *Rheum* available at the site and other plants in these habitats is discussed by Pantoja and Kuhl (2009).

Depending on site and years, queens were the most abundant caste collected. The lowest collecting year was 2010 and the location with the fewest was Fairbanks where only 57 specimens were collected. Delta Junction displayed the highest overall queen density. It will be reasonable to assume that the removal of queens during the previous season (2009) would reduce the overall bumble bee relative density during the following season (2010). However, this was not observed, more queens were captured in Delta Junction during 2010 than 2009 (Table 4.2); therefore, the reduction in the relative population density of workers and males recorded for Delta Junction during the 2010 season as compared to the 2009 season cannot be explained by sampling or removal of the queens. In their Oregon study, Stephen and Rao (2005) did not distinguish between castes, but did mention collecting 70.1% females during their study.

Specimens collected in low densities (less than 15 specimens collected) include *B. balteatus*, *B. rufocinctus* and *B. borealis*. These species were not observed in flight except for *B. borealis,* seen on a bank of the Tanana River southwest of Fairbanks foraging on a species of *Antennarias*. Only three specimens of *B. borealis* were collected at the Fairbanks site. This species hasn't been reported north of Manitoba (Sam Droege, United States Geological Society Patuxent Wildlife Research Center, pers. comm.); however, this species was present in the UAM (2010) collection (unpublished data). One verified specimen was collected from Toklat River, near the bridge on Park Road in Denali National Park and another unverified specimen was collected from Agattu Island (S. Huguet, pers. comm.). It is possible that the *B. borealis* specimen from Agattu Island is a misidentification of *B. distinguendus*.

This study used one trapping method based on color attractiveness (Stephen and Rao 2005). Species not attracted to this trap might not have been collected; however, Stephen and Rao (2005) mention that bee captures in Oregon with blue vane traps were consistent with the bee fauna documented using a variety of collection methods at each site during the test periods. Additional sampling studies on *Bombus* in Alaska need to be conducted to further understand the effectiveness of the chosen sampling method and identify species that might not be attracted to this sampling method.

The discovery of *Nosema* and nematodes in bumble bees from the Fairbanks area represents the first report of these two parasites from the state (Table 4.5). In a recent paper, Schmid-Hempel and Tognazzo (2010) described a protozoan flagellate, *Crithidia bombi* in Alaskan bumble bees. Washburn (1963) reported on bumble bee parasites, but his report was limited to the social hymenopteran parasites in the *Psithyrus* group, not endoparasites. Reports are conflicting on whether *Nosema* is native to North America as well as the virulence of the microsporidian on bumble bees. In Ontario, Canada, *Nosema* introductions are most likely associated with imported bumble bees that escaped green houses (Colla et al. 2006). However, others have shown that bumble bees can become infected by *Nosema* from honey bees (Plischuk et al. 2009).

Nosema and nematodes were collected from species that were collected in high numbers in the Fairbanks traps. The sampling effort obtained too few specimens of the relatively low abundant species; therefore one cannot assume that *B. centralis*, *B. occidentalis*,

and *B. perplexus* are the only species in Alaska infected with the endoparasites from this study. Studies are needed to determine the species of *Nosema* identified from this study in Alaska, the effect of the parasite on bumble bee biology, and the prevalence of the parasites on the major bumble bee species in each geographical area.

Bombus occidentalis was once considered to be one of the most common west coast bumble bee species is declining in the Pacific North West (Rao and Stephen 2007). In Alaska, this species represented roughly 10% of the total specimens collected (Tables 4.2-4.4) and was within the top five most abundant species both years in all locations, suggesting that *B. occidentalis* is a relatively abundant species in the areas studied. However, *B. occidentalis* specimens tested positive for *Nosema* (Table 4.5). Several authors (Whittington and Winston 2004; Thorp 2005; Thorp and Shepherd 2005) have proposed that the recent catastrophic decline throughout North America in *B. occidentalis* is due to *Nosema*, suggesting the need to study the parasitic loads of bumble bees in Alaska. Social parasites of *B. occidentalis* include *B. suckleyi, B. insularis,* and *B. fernaldae* (Thorp et al. 1983), all of which occur in Alaska (Washburn 1963). Further monitoring can determine the status and health of this species in Alaska.

Three of the 17 species collected are cuckoo bumble bees (social parasites): *B. ashtoni, B. fernaldae*, and *B. insularis*. Two of the species, B. *fernaldae* and *B. insularis* were recovered from the three sites surveyed; while *B. ashtoni* was not recorded from the Fairbanks area. With the exception of the Palmer location, relative densities of cuckoo bumble bees were below six percent. During 2010, relative densities of *B. ashtoni, B. fernaldae*, and *B. insularis* were 5.7, 5.8, and 6.75 respectively. Washburn (1963) reported on bumble bee parasites in Alaska and provided distribution data on some of the parasites, but did not provided data on relative insect densities. Research is needed to better understand the effects of social parasites on other bumble bee species. Similarly, research is needed to study the geographical extent of nematodes infecting bumble bees in Alaska. Tetradonematid nematodes are obligate and fairly specific parasites (P. Stock, pers. comm.), but are not considered common nematodes of bumble bees and usually do not reach serious proportions (Poinar 1975).

Many species were collected in low densities at all locations including *B. balteatus, B. moderatus, B. rufocinctus*, and *B. sylvicola*. Little is known about the biology and population of these species under Alaskan conditions. Previous reports (Washburn 1963) provided limited

information on a few of the species collected in low densities in this study. However Washburn (1963) only provided the year and the site where the species were collected, but no data on the species relative densities at each site or year. Additional research is needed to study the biology and geographical distribution of *B. balteatus*, *B. moderatus*, *B. rufocinctus*, and *B. sylvicola* in other areas of the state not covered in this study.

CHAPTER 6. CONCLUSION

Major world pollinators include bees, beetles, flies, butterflies, birds, and bats, all of which help pollinate over 75% of Earth's flowering plants and nearly 75% of our crops (US FS and USDA 2010). In the subarctic region, bumble bees are considered to be the most important pollinators (Washburn 1963; Kevan 1972); however, immediate concerns involving climate change, colony collapse disorders in honey bees, and lack of faunistic insect studies in Alaska emphasize the need to study bumble bee biology in Alaska. Seventeen species of bumble bees were identified from three localities in Alaska which included: *B. ashtoni*, *B. balteatus,* B. *bifarius*, *B. borealis*, *B. centralis*, *B. fernaldae*, *B. flavifrons*, *B. frigidus*, *B. insularis*, *B. jonellus*, *B. melanopygus*, *B. mixtus*, *B. moderatus*, *B. occidentalis*, *B. perplexus*, *B. rufocinctus*, and *B. sylvicola*.

Not all species were recovered from all localities and species richness and relative abundances varied by year. Overall, the most common bumble bees near agricultural lands include *B. centralis, B. frigidus, B. jonellus, B. melanopygus, B. mixtus,* and *B. occidentalis* and their population and local diversity can be highly variable from year to year. The highest relative insect abundance was documented in Delta Junction with 50% of the total number of specimens collected both years, followed by Fairbanks and Palmer with 25.8% and 23.7% of the overall catch respectively. Species richness was similar between locations with fifteen species from Delta Junction, fourteen from Palmer and fifteen species from the Fairbanks area.

Bumble bees were found to be infected by endoparasites to include *Nosema* spp. and nematodes. Social hymenopteran parasites were collected from all locations studied. The species of social parasites included, *B. ashtoni*, *B. fernaldae*, and *B. insularis*.

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Appendix A. Synonyms and Taxonomic Notes

Species	Synonyms	Taxonomic Notes
B. appositus		Could be a misidentification of *B. borealis* since Western keys generally do not include *B. borealis* (J. Strange, pers. comm.).
B. ashtoni		Status requires investigation (Ascher and Pickering 2010).
B. balteatus	*Megabombus kirbyellus* (Milliron 1973; Williams and Batzli 1982); *Bombus kirbyellus* Curtis (Bequaert 1920; Washburn 1963); *Psithyrus tricolor* Franklin (Ashmead 1902)	Considered conspecific with *B. kirbyellus* by most, although Milliron (1973) considered them separate species in Alaska (Thorp et al. 1983; Williams 1998).
B. californicus	*Megabombus fervidus californicus* (Smith) (Milliron 1973); *Bombus californicus* Smith (Bequaert 1920); *Bombus neglectulus sp.nov.* (Ashmead 1902)	*Bombus fervidus* and *B. californicus* sometimes regarded as conspecific and as separate species, but Williams (1998) treats them as parts of a single variable species (Williams 1998); further investigation warranted in Alaska (Ascher and Pickering 2010); Ascher and Pickering (2010) suggests that *B. neglectulus* is a synonym of *B. californicus.*
B. distinguendus		Reported in outer Aleutians (Williams and Thomas 2005).
B. fernaldae		Might be conspecific with *B. flavidus* (Williams 1998); most common parasitic associations with *Pyrobombus* (Thorp et al. 1983).

Appendix A. Continued – Synonyms and Taxonomic Notes

Species	Synonyms	Taxonomic Notes
B. flavifrons	*Bombus pleuralis* Nylander (Bequaert 1920; Washburn 1963; UAM 2010); *Bombus juxtus* Cresson (Ashmead 1902)	*Bombus pleuralis* is the oldest name available, but rarely ever used (Williams 1998); Baquaert (1920) suggests *B. juxtus* identified by Ashmead in 1902 was a synonym of *B. pleuralis*.
B. frigidus	*Bombus couperi* Cresson (Ashmead 1902)	Baquaert (1920) suggests *B. couperi* identified by Ashmead in 1902 was a synonym of *B. frigidus.*
B. hyperboreus	*Megabombus hyperboreus* (Milliron 1973; Williams and Batzli 1982)	Workers rarely found (Milliron 1973); *B. arcticus* is most likely to be conspecific with *B. hyperboreus* (Williams 1998); *B. hyperboreus* is thought to be a social parasite in colonies of *B. polaris* at least facultatively (Williams 1998).
B. insularis	*Psithyrus consultus* Franklin (Bequaert 1920); *Bombus crawfordi* (Franklin) (Washburn 1963)	Most common parasitic associations with *Pyrobombus, Subterraneobombus,* and *Cullumanobombus* (Thorp et al. 1983).
B. jonellus	*Bombus alboanalis* Franklin (Ashmead 1902; Bishop 1992; Bishop and Armbruster 1999; Ascher and Pickering 2010; Washburn 1963)	*Bombus alboanalis* morphologically similar to *B. jonellus*, but treated as single variable species (Williams 1998); *B. alboanalis* has been regarded as separate species and conspecific with *B. frigidus* or *B. jonellus* (Williams 1998); some Alaskan specimens cited as *B. alboanalis* (UAM 2010).
melanopygus	*Bombus edwardsii* Cresson (Ashmead 1902)	Conspecific to *B. edwardsii* (Williams 1998).

Appendix A. Continued – Synonyms and Taxonomic Notes

Species	Synonyms	Taxonomic Notes
B. mixtus	*Bombus oregonensis* Cresson (Ashmead 1902)	Baquaert (1920) suggests *B. oregonesis* identified by Ashmead in 1902 was a synonym of *B. frigidus.*
B. moderatus	*Bombus lucorum* (Linnaeus) (Ashmead 1902; Bequaert 1920; Milliron 1971; Williams and Batzli 1982; Ascher and Pickering 2010; CNC 2010; UAM 2010); *Bombus terrestris* (Linnaeus) (Davis 2002)	*Bombus moderatus* was sometimes mis-identified as *B. lucorum* which was also sometimes lumped with *B. terrestris*, however, *B. moderatus* is now a clearly defined taxon, characterized by morphology and DNA markers (Bertsch et al. 2010); Cameron et al. (2007) suggests there is a genetic divergence between *B. moderatus* and *B. lucorum* of about 2.1%.
B. neoboreus	*Megabombus strenuus* Cresson (Milliron 1973; Williams and Batzli 1982); *Bombus strenuus* Cresson (Ashmead 1902; Washburn 1963; CNC 2010)	
B. occidentalis	*Bombus terricola occidentalis* Greene (Milliron 1971)	Separate species from *B. terricola* (Thorp et al. 1983); suffered dramatic decline across much of the western part of its range (Evans et al. 2009).
B. polaris	*Megabombus polaris* (Curtis) (Milliron 1973; Williams and Batzli 1982); *Bombus kincaidii* Cockerell (Ashmead 1902; Washburn 1963); *Bombus arcticus* Kirby (Ashmead 1902)	*Bombus arcticus* is a synonym for *B. polaris,* but not frequently used (Williams 1998).

Appendix A. Continued – Synonyms and Taxonomic Notes

Species	Synonyms	Taxonomic Notes
B. sandersoni		Maybe a mis-identification since the closest population of *B. sandersoni* is over 2000 miles away which would be a significant (and unlikely) range extension (J. Strange, pers. comm.); species typically in high elevation portions of the Appalachians (S. Droege, pers. comm.).
B. suckleyi		Closely related to *B. ashtoni* and most common parasitic associations with *Pyrobombus* and *Bombus* (Thorp et al. 1983); when reviewing UAM specimens identified by Krombein 1957-1961 during this project, there was no noticeable difference between *B. suckleyi* and *B. ashtoni.*
B. sylvicola	*Bombus gelidus* Cresson (Bequaert 1920); *Bombus lapponicus* (Fabricius) (Ascher and Pickering 2010; CNC 2010; UAM 2010)	Morphologically similar to *B. lapponicus* and been suggested they are conspecific (Thorp et al. 1983), but DNA comparison from 16S gene shows they could be two separate species (Williams 1998); Ascher and Pickering (2010) suggests that *B. gelidus* is a synonym of *B. sylvicola.*
B. vagans		Possibly only exists in the southeast Alaska panhandle (S. Droege, pers. comm.).

Appendix B. Distinguishing Features.

Species	Frons	Vertex	Thorax	Tergite descriptions	Other
B. appositus	yellow	yellow	yellow with a black band between the wings	T1-T5 yellow/blonde/brown; T6 black with few hairs	
B. ashtoni	black	black	posterior half of thorax is yellow while the anterior half is black (sometimes with yellow hairs intermixed)	T1 usually yellow, but sometimes black; T2 black; T3 black with yellow hair laterally; T4 yellow; T5 black with yellow hair laterally; T6 black and shiny (in males, T1 and T4 pale yellow; T2-T3 black; T5-T6 black, but can have yellow hair laterally)	in males, flagellomeres 1-3 longer than basal segment
B. balteatus	black	black	yellow with a black band between the wings that extends below the wing bases	T1 -T2 yellow; T3 black; T4-T5 rust or orange; T6 dull with black and orange hairs	clypeus with punctures
B. bifarius	yellow	yellow	yellow thorax with a black band between the wings that extends below the wing base; the black also typically extends into an anterior v-shape	T1 yellow sometimes with a few black hairs; T2 black that typically extends into a v-shape; T3 orange sometimes with black hairs; T4 mainly yellow; T5 black; T6 dull with few black hairs	orange corbiculae fringe

Appendix B. Continued – Distinguishing Features.

Species	Frons	Vertex	Thorax	Tergite descriptions	Other
B. borealis	black	black	yellow with a black band between the wings	T1-T4 yellow/blonde; T5 yellow of blonde with black hairs; T6 dull and black	clypeus smooth and shiny
B. californicus	unsure	unsure	yellow with a black band between the wings	T1 yellow; T2-T3 black with possible traces of orange; T4 yellow; T5-T6 unsure	
B. centralis	yellow possibly with black hairs intermixed	yellow possibly with black hairs intermixed	yellow with some black hairs intermixed and black between the wings	T1-T2 yellow; T3 rust; T4 rust or orange; T5-T6 black	
B. distinguendus	black	black	yellow with a black band between the wings	T1-T4 yellow/blonde; T5 yellow of blonde with black hairs; T6 smooth and shiny	possibly only found in the Aleutian Islands

Appendix B. Continued – Distinguishing Features.

Species	Frons	Vertex	Thorax	Tergite descriptions	Other
B. fernaldae	black	yellow	yellow with a black spot between the wings (in males, anterior half is black)	T1 black or yellow; T2 black; T3 black; T4 yellow; T5 black; T6 dull and black (in males, T1 and T4 yellow; T2-T3 and T5 black; T6-T7 black but sometimes with yellow hair laterally)	in males, flagellomeres 1 and 3 equal in length
B. flavifrons	mainly yellow with black hairs intermixed	mainly yellow with black hairs intermixed	olive/cloudy with black interalar band between the wings	T1 -T2 yellow sometimes with a black hairs in a v-shape pointing to anterior end; T3- T6 black but sometimes with rust colored hairs intermixed	ventral side of bee with yellow hairs
B. frigidus	black	yellow	yellow with a black band between the wings	T1-T2 dense yellow; T3 black; T4 completely orange or with some black; T5-T6 rust or orange	corbiculae fringe made of black and orange hairs
B. hyperboreus	black	black	yellow with a black band between the wings that extends below the wing bases	T1-T2 yellow; T3-T5 black; T6 black or hairless	ventral side of bee completely black

Appendix B. *Continued* – Distinguishing Features.

Species	Frons	Vertex	Thorax	Tergite descriptions	Other
B. insularis	black with some yellow intermixed	black with some yellow intermixed	yellow with black spot between the wing bases (in males, anterior half can be black)	T1-T2 black; T3-T5 black or hairless with yellow hair laterally not medially; T6 black and shiny (in males, T1-T4 yellow; T5-T7 black with a small amount of yellow on T6 laterally)	
B. jonellus	black	yellow	yellow with a black band between the wing bases	T1-T2 thin yellow hairs; T3 black; T4-T6 white or blonde hairs	
B. melanopygus	olive or clouded	olive or clouded	posterior half of the thorax is clouded, more olive with a black band between the wing bases and the anterior half of thorax with more yellow	T1 yellow; T2-T3 rust; T4 yellow; T5-T6 black with or without sparse yellow hairs	in males, yellow hair above antennal bases
B. mixtus	olive	olive	thorax typically more olive than yellow with black band or spot between the wing bases	T1-T2 predominately black with yellow hair centrally; T3 predominately black with some light yellow or rust hairs; T4 all rust or orange; T5-T6 black or with some blonde hairs	corbiculae fringe black

Appendix B. Continued – Distinguishing Features.

Species	Frons	Vertex	Thorax	Tergite descriptions	Other
B. moderatus	black	black	yellow above wing bases and black between and below wing bases	T1 black; T2 yellow or blonde; T3 black; T4-T5 white; T6 black or with few white hairs	
B. neoboreus	black	varies	yellow with black band that extends below the wing bases	T1-T3 yellow; T4 most often black, but can be orange or with orange hairs laterally; T5 most often black, but can be orange or with orange hairs laterally; T6 black or with few hairs	
B. occidentalis	black or with yellow hairs intermixed	black or with yellow hairs intermixed	posterior half of thorax yellow with black band between the wing bases that extends below the wing bases; anterior half of thorax black with some yellow/olive hairs or all black	T1-T2 black; T3 yellow; T4 black; T5 white, sometimes more yellow/blonde/white; T6 black with some blonde hairs (in males, T1-T2 black; T3-T4 yellow; T5 black sometimes with yellow; T6-T7 yellow/blonde/white)	corbiculae fringe orange

Appendix B. Continued – Distinguishing Features.

Species	Frons	Vertex	Thorax	Tergite descriptions	Other
B. nevadensis	varies	varies	yellow with black band that extends below the wing bases	T1-T3 yellow; T4-T6 black	black below tegula; ocelli below supraorbital line; in males, flagellomeres 1 as long as 2 & 3
B. perplexus	black	yellow	yellow possibly with a small black spot between the wing bases	T1-T2 yellow; T3-T5 black; T6 black or with few blonde hairs	
B. polaris	black	black	yellow with a black band between the wings that extends below the wing bases	T1-T2 yellow; T3 black; T4-T5 rust or orange; T6 black or few hairs	clypeus smooth or with very few punctures
B. rufocinctus	mainly black	yellow	yellow thorax with a black spot between the wing bases	T1 black possibly with a few yellow hairs; T2-T3 black; T4-T5 yellow; T6 black or with few blonde hairs (in males, T1-T2 yellow, T3-T4 black, T5-T6 yellow, T7 black)	in males, flagellomere 2 shorter than 3 while 1-3 & basal segment equal in length

Appendix B. Continued – Distinguishing Features.

Species	Frons	Vertex	Thorax	Tergite descriptions	Other
B. sitkensis	olive	olive	black with the outside edge olive that extends below wing bases	T1-T2 yellow; T3 black, sometimes with yellow hairs intermixed; T4-T5 black; T6 black with some blonde hairs	
B. suckleyi	black	yellow	top half of thorax is yellow while the bottom half is black (sometimes with yellow hairs intermixed)	T1 black or yellow; T2 black; T3 black with yellow hair laterally, sometimes even medially; T4 yellow; T5 black with yellow hair laterally, sometimes even medially; T6 black and shiny	
B. sylvicola	yellow	yellow	yellow thorax with a black band between the wings that extends below the wing base; the anterior black also typically extends into a v-shape	T1 yellow; T2-T3 rust, sometimes with black hairs mid-segment; T4 yellow, sometimes with black hairs mid-segment; T5-T6 black with sparse yellow hairs	black corbiculae fringe; in males, very little yellow hairs above antennal bases
B. vagans	black	black	yellow with a black band between the wing bases	T1 yellow, sometimes mostly hairless; T2 yellow; T3-T6 black	ventral side of bee completely black

Appendix C. Gardening for Bees.

Plant a wide variety of native plants that bloom from early spring into late fall.

Choosing native shrubs and flowers that have continuous blooms will provide continuous forage. Using native plants can reduce the invasion of non-native plant species. Plant a variety of flower shapes and colors to encourage a diversity of bumble bee species. Also avoid hybrid flowers since they are typically bred for appearance rather than pollen and nectar availability.

Limit chemical use.

Choosing non-chemical or organic solutions to combat insect/weed problems can reduce toxic and deadly encounters for the bees.

Leave hollow trees or walls or clumps of grass.

Bumble bee nesting sites are most often underground in abandoned rodent holes, but they can also find shelter in hollow trees, or under a clump of grass.

Remove invasive plants that can reduce native forage sites.

Invasive monocultures can degrade natural habitat and can reduce pollinator populations. A diversity of floral shapes and colors are important because they appeal to different species.

Leave some areas untilled or lawn uncut.

These areas provide great nesting and forage sites. The turning of the soil can destroy ground nests that are present at that depth and hinders the emergence of bees that are nesting deeper in the ground. Uncut lawns allow for native wildflowers to bloom and provide great foraging sites.

Provide a source of water.

A source of water, important for all living things, could be provided via a birdbath, fountain, dripping faucet, small pond or simply a mud puddle. Sea salt or wood ashes added into mud puddles could provide bees with their mineral requirements.

(Adapted from NRCS 2005)